ENGINEERING DRAWING

THOMAS E. FRENCH

ENGINEERING DRAWING

A MANUAL

OF

ENGINEERING DRAWING

For Students and Draftsmen

BY

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PREFACE TO THE SIXTH EDITION

In the successive editions of this book the aim has been to keep abreast of modern engineering practice, adding new material in text and problems with each revision. Quoting from the previous preface, a course in drawing consists essentially of a series of problems given in connection with assigned study of the text. The value of the course lies in the selection, arrangement and method of presentation of these problems, each chosen to illustrate and apply some particular teaching point. In this edition the favorite problems of the previous edition have been retained and many new ones added, all representing current design. The page size has been enlarged, allowing an increase in the size of the illustrations, the number of which has grown from 811 to 1062.

Because of their particular timeliness, it is believed that the new chapters on aircraft drawing, jig and fixture drawing and welding drawing will be appreciated, as will the expansion of the former article on "the drawings and the shop" into a separate chapter of the same title. Since the last revision, and especially in the past year, the American Standards Association has adopted numerous new standards, of which those of concern to designers have been tabulated for easy reference. The new material in text and appendix will, it is hoped, make not only a better work book for class use but also a more valuable reference book for the engineer's technical library.

The author is indebted to the teachers of drawing over the country, many of whom are his personal friends, for helpful suggestions and encouraging comment and to engineers in the industries for valuable ideas. John M. Russ has again contributed to the problems, H. M. McCully and W. H. Rasche have given constructive criticism and C. T. Reid of the Douglas Aircraft Company has checked the aircraft chapter. The interest and assistance of the author's colleagues in the department, L. D. Jones, C. D. Cooper, H. H. Brittingham, G. H. Coddington, P. E. Machovina, A. J. Philby and H. W. Shupe are recorded with appreciation, as is also the contribution of J. N. Edmondson to the jig and fixture chapter and the fine collaboration of C. J. Vierck.

T. E. F.

COLUMBUS, OHIO,
April, 1941.

PREFACE TO THE FIRST EDITION

There is a wide diversity of method in the teaching of engineering drawing, and perhaps less uniformity in the courses in different schools than would be found in most subjects taught in technical schools and colleges. In some well-known instances the attempt is made to teach the subject by giving a series of plates to be copied by the student. Some give all the time to laboratory work; others depend principally upon recitations and home work. Some begin immediately on the theory of descriptive geometry, working in all the angles; others discard theory and commence with a course in machine detailing. Some advocate the extensive use of models; some condemn their use entirely.

Different courses have been designed for different purposes, and criticism is not intended, but it would seem that better unity of method might result if there were a better recognition of the conception that drawing is a real language, to be studied and taught in the same way as any other language. With this conception it may be seen that except for the practice in the handling and use of instruments, and for showing certain standards of execution, copying drawings does little more in the study as an art of expression of thought than copying paragraphs from a foreign book would do in beginning the study of a foreign language.

And it would appear equally true that good pedagogy would not advise taking up composition in a new language before the simple structure of the sentence is understood and appreciated; that is, "working drawings" would not be considered until after the theory of projection has been explained.

After a knowledge of the technic of expression, the "penmanship and orthography," the whole energy should be directed toward training in constructive imagination, the perceptive ability which enables one to think in three dimensions, to visualize quickly and accurately, to build up a clear mental image, a requirement absolutely necessary for the designer who is to represent his thoughts on paper. That this may be accomplished more readily by taking up solids before points and lines has been demonstrated beyond dispute.

It is then upon this plan, regarding drawing as a language, the universal graphical language of the industrial world, with its varied forms of expression, its grammar and its styles, that this book has been built. It is not a "course in drawing," but a text-book, with exercises and problems in some variety from which selections may be made.

Machine parts furnish the best illustrations of principles, and have been used freely, but the book is intended for all engineering students. Chapters on architectural drawing and map drawing have been added, as in the interrelation of the professions every engineer should be able to read and work from such drawings.

In teaching the subject, part of the time, at least one hour per week, may profitably be scheduled for class lectures, recitations, and blackboard work, at which time there may be distributed "study sheets" or home plates of problems on the assigned lesson, to be drawn in pencil and returned at the next corresponding period. In the drawing-room period, specifications for plates, to be approved in pencil and some finished by inking or tracing, should be assigned, all to be done under the careful supervision of the instructor.

The judicious use of models is of great aid, both in technical sketching and, particularly, in drawing to scale, in aiding the student to feel the sense of proportion between the drawing and the structure, so that in reading a drawing he may have the ability to visualize not only the shape but the size of the object represented.

In beginning drawing it is not advisable to use large plates. One set of commercial drafting-room sizes is based on the division of a 36″ × 48″ sheet into 24″ × 36″, 18″ × 24″, 12″ × 18″, and 9″ × 12″. The size 12″ × 18″ is sufficiently large for first year work, while 9″ × 12″ is not too small for earlier plates.

Grateful acknowledgment is made of the assistance of Messrs. Robert Meiklejohn, O. E. Williams, A. C. Harper, Cree Sheets, F. W. Ives, W. D. Turnbull, and W. J. Norris of the staff of the Department of Engineering Drawing, The Ohio State University, not only in the preparation of the drawings, but in advice and suggestion on the text. Other members of the faculty of this University have aided by helpful criticism.

The aim has been to conform to modern engineering practice, and it is hoped that the practical consideration of the draftsman's needs will give the book permanent value as a reference book in the student's library.

The author will be glad to cooperate with teachers using it as a textbook.

T.E.F.

COLUMBUS, OHIO,
June 6, 1911.

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ENGINEERING DRAWING

CHAPTER I

INTRODUCTORY

1. By the term "engineering drawing" is meant drawing as used in the industrial world by engineers and designers, the graphic language in which are expressed and recorded the ideas and information necessary for the building of machines and structures; as distinguished from drawing as a fine art, as practiced by artists in pictorial representation.

The artist strives to produce, from either the model or landscape before him or through his creative imagination, a picture which will impart to the observer something as nearly as may be of the same mental impression as that produced by the object itself, or as that in the artist's mind. As there are no lines in nature, if he is limited in his medium to lines instead of color and light and shade, he is able only to suggest his meaning and must depend upon the observer's imagination to supply the lack.

The engineering draftsman has a greater task. Limited to outline alone, he may not simply suggest his meaning but must give exact and positive information regarding every detail of the machine or structure existing in his imagination. Thus drawing to him is more than pictorial representation; it is a complete graphical language, by whose aid he may describe minutely every operation necessary and may keep a complete record of the work for duplication or repairs.

In the artist's case the result can be understood, in greater or less degree, by anyone. The draftsman's result does not show the object as it would appear to the eye when finished; consequently his drawing can be read and understood only by one trained in the language.

Thus as the foundation upon which all designing is based, engineering drawing becomes, with perhaps the exception of mathematics, the most important single branch of study in a technical school. Every engineering student must know how to make and how to read drawings. The subject is essential in all types of engineering practice. The drafting room is often the entering gateway into industry, but even one who may never have to make drawings must be able to interpret them and to know whether or not a drawing is correct. An engineer without a working knowledge of the engineers' language would be professionally illiterate.

2. To write this language easily and accurately the aid of mathematical instruments is required, and when thus written it is called "mechanical

drawing."[1] When done with the unaided hand, without the assistance of instruments or appliances, it is known as "freehand drawing" or "technical sketching." Training in both of these methods is necessary for the engineer, the first to develop accuracy and manual dexterity, the second to train in comprehensive observation and to give control and mastery of form and proportion.

Our object then is to study this language so that we may write it, express ourselves clearly to one familiar with it, and read it readily when written by another. To do this we must know its alphabet, its grammar and its composition, and be familiar with its idioms, accepted conventions and abbreviations.

This new language is entirely a graphical or written one. It cannot be read aloud but must be interpreted by forming a mental picture of the subject represented; and the student's success in it will be indicated not alone by his skill in execution but by his ability to interpret his impressions, to visualize clearly in space.

It is not a language to be learned only by the comparatively few draftsmen who will be professional writers of it but, as already indicated, should be understood by all connected with or interested in technical industry; and the training its study gives in quick, accurate observation and the power of reading description from lines is of a value quite unappreciated by those not familiar with it.

In this study we must first of all become familiar with the technique of expression, and, as instruments are used for accurate work, the first requirement is the ability to use these instruments correctly. With continued practice will come a facility in their use which will free the mind from any thought of the means of expression. Under technique is included the study of lettering, usually the first work taken up in a technical course.

[1] The term "mechanical drawing" is often applied to all industrial graphics and, although an unfortunate misnomer, has the sanction of long usage. The whole subject of graphic representation of solids on reference planes comes under the general name of "descriptive geometry." That term, however, has by common acceptance been restricted to a somewhat more theoretical treatment of the subject as a branch of mathematics. This book may be considered as an ample preparation for that fascinating subject, with whose aid many difficult problems may be solved graphically.

CHAPTER II

THE SELECTION OF INSTRUMENTS

3. In the selection of instruments and materials for drawing, the only general advice that can be given is to secure the *best* that can be afforded. For one who expects to do work of professional grade it is a great mistake to buy inferior instruments. Sometimes a beginner is tempted by the suggestion that he get cheap instruments for learning, with the expectation of getting better ones later. With reasonable care a set of good instruments will last a lifetime, while poor ones will be an annoyance from the start and will be worthless after short usage. As poor instruments look so much like good ones that an amateur is unable to distinguish them, trustworthy advice should be sought before buying.

This chapter will be devoted to a short description of the instruments usually necessary for drawing. Mention of some others not in everyday use but convenient for special work will be found in Chap. XXX.

4. Check List of Instruments and Materials.

1. Set of drawing instruments, in leather case, including at least: 6″ compasses, with fixed needle-point leg, pencil, pen and lengthening bar; 6″ hairspring dividers; two ruling pens; three bow instruments; box of hard leads.
2. Drawing board.
3. T-square.
4. 45° and 30°-60° triangles.
5. 12″ mechanical engineer's scale of proportional feet and inches (three flat or one triangular).
6. Slide rule.
7. Thumbtacks, or Scotch tape.
8. Drawing pencils: 6H, 2H and F.
9. Pencil pointer (sandpaper or file).
10. Pencil eraser.
11. Bottle of drawing ink.
12. Bottleholder.
13. Penholder, pens for lettering, and penwiper.
14. French curves.
15. Drawing paper to suit.
16. Tracing paper.

To these may be added:

17. Artgum or cleaning rubber.
18. Dusting cloth.
19. Erasing shield.
20. Lettering triangle.
21. Protractor.
22. Civil engineer's scale.
23. 2′ folding, or 6′ flexible rule.
24. Sketchbook.
25. Hard Arkansas oilstone.
26. Piece of soapstone.
27. Sharp pocketknife, or sharpener (for sharpening pencils).

The student should mark all his instruments and materials plainly with initials or name, as soon as purchased and approved.

(1) **The Case Instruments.**—All modern high-grade instruments are made with some form of "pivot joint," originally patented by Theodore

Alteneder in 1850 and again in 1871. Older instruments (and some cheap modern ones) were made with tongue joints, but the wear of the tongue on the pin resulted in a lost motion which after a time rendered the instrument unfit for use. In the pivot joint the wear is on adjustable conical points. The Alteneder joint and several modifications of it by other manufacturers are shown in Fig. 1.

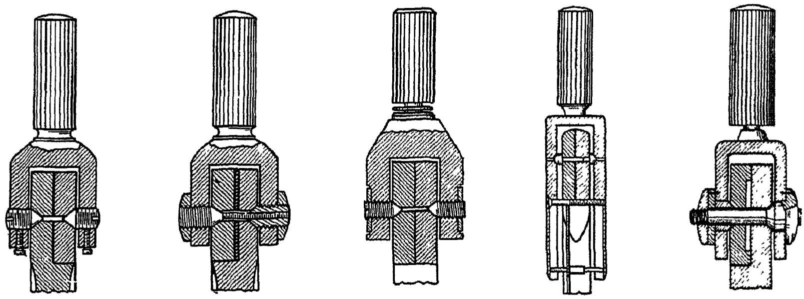


FIG. 1.—Sections of pivot joints.

The handle attached to the yoke, although not essential to the working of the joint, is very convenient. Not all instruments with handles, however, are pivot-joint instruments. Several straightener devices for keeping the handle erect have been devised, but by many draftsmen they are not regarded with favor.

There are three different patterns or shapes in which modern compasses are made; the beveled, or American (*A*); the round (*B*), and the flat (*C*),

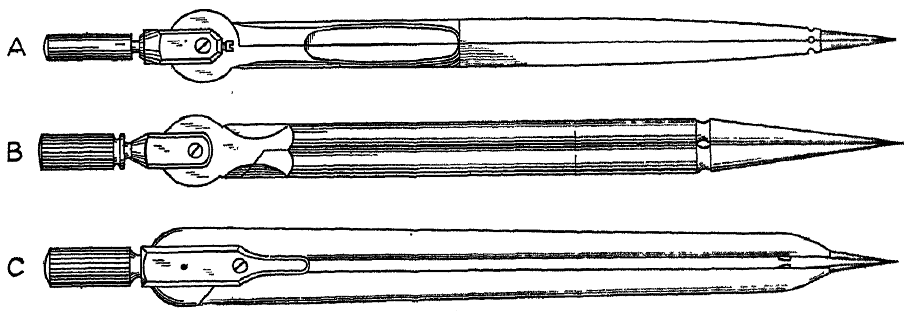


FIG. 2.—The three patterns.

Fig. 2. The choice of shapes is entirely a matter of personal preference. After one has become accustomed to the balance and feel of a certain instrument, he will not wish to exchange it for another shape.

Compasses may be tested for accuracy by bending the knuckle joints and bringing the points together, as in Fig. 3. If out of alignment, they should not be accepted. The standard compasses are 6 inches long, but a favorite additional instrument with draftsmen is the 4-inch size with fixed pencil leg and its companion with fixed pen leg.

Dividers are made either "plain," as those in Fig. 2, or "hairspring" as shown in Fig. 4. The latter form, having a screw for fine adjustment, is occasionally of convenience and is to be preferred. Compasses may also be had with hairspring attachment on the needle-point leg.

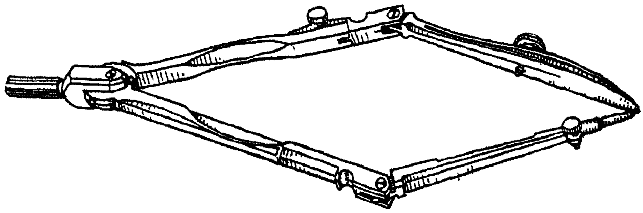


FIG. 3.—Test for alignment.

Ruling pens are made in a variety of forms, Fig. 5. The two most popular ones are the spring blade (A), which opens sufficiently wide for cleaning, and the jackknife (E), which may be cleaned without changing

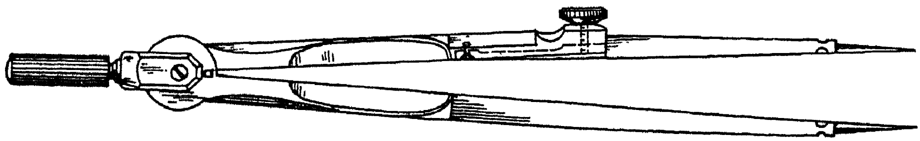


FIG. 4.—Hairspring dividers.

the setting. The form shown at (F) is known as a "detail pen" or "Swede pen," which for large work is a very desirable instrument. The nibs of the pens should be shaped as shown in Fig. 36. Pens sometimes come from

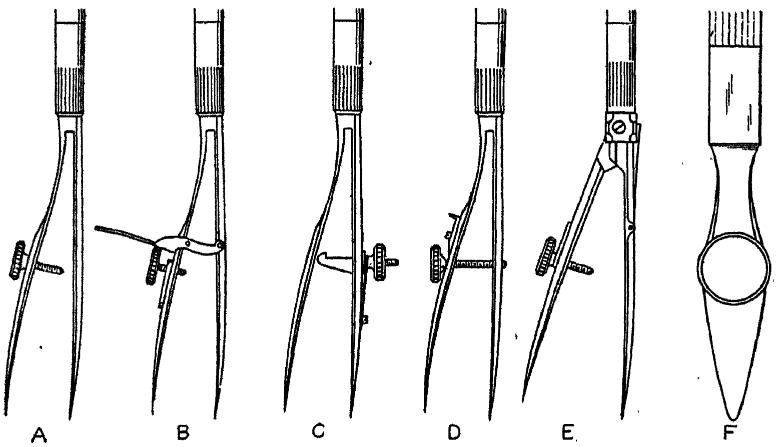


FIG. 5.—Ruling pens, opened for cleaning.

the factory poorly sharpened and must be dressed as described on page 22 before they can be used.

The set of three spring-bow instruments includes bow points or spacers, bow pencil and bow pen. There are several designs and sizes. The

standard shapes of side-screw bow instruments are shown in Fig. 6*A*, *B*, *C*. At *D* is illustrated the hook or ring-spring type, sometimes called "Richter" bows. Both standard and Richter types are made as side-screw bows and also as center-screw instruments, illustrated by the center-screw bow pen at *E*. These are becoming increasingly popular among draftsmen. The springs of the side-screw bows should be strong enough to open to the full

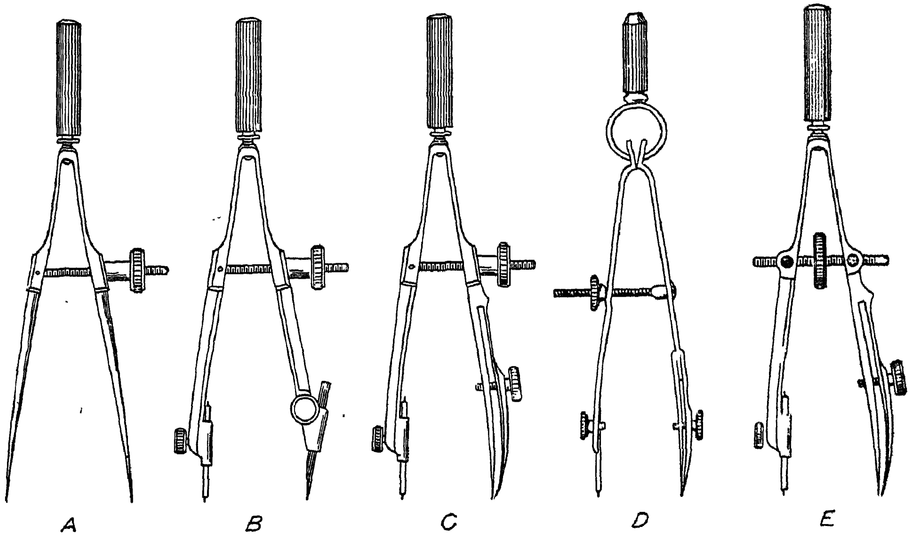


Fig. 6.—Spring bow instruments.

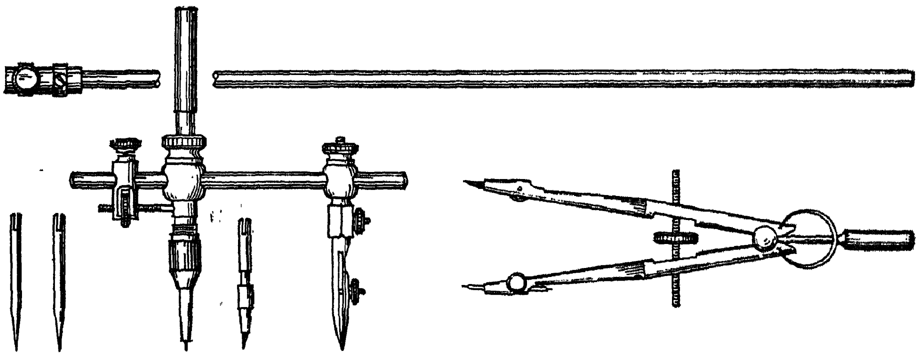


Fig. 7.—Automotive, or detailer's, set.

length of the screw but not so stiff as to be difficult to pinch together. The hook-spring bow usually has a softer spring than the flat-spring type.

A comparatively new combination of drawing instruments that has been received favorably, particularly in the automotive industry, is shown in Fig. 7. It consists of a large, sturdy bow instrument sometimes with interchangeable pen, pencil and spacer points; along with a tubular beam compass for large circles. The compass pen inserted in a handle provides a ruling pen.

(2) **Drawing boards** should be made of clear white pine, cleated to prevent warping. Care should be taken in their selection, and the working edge should be tested with a steel straightedge.

(3) **The T-square** with fixed head, Fig. 8*A*, is used for all ordinary work. It should be of hardwood, and the blade should be perfectly straight.

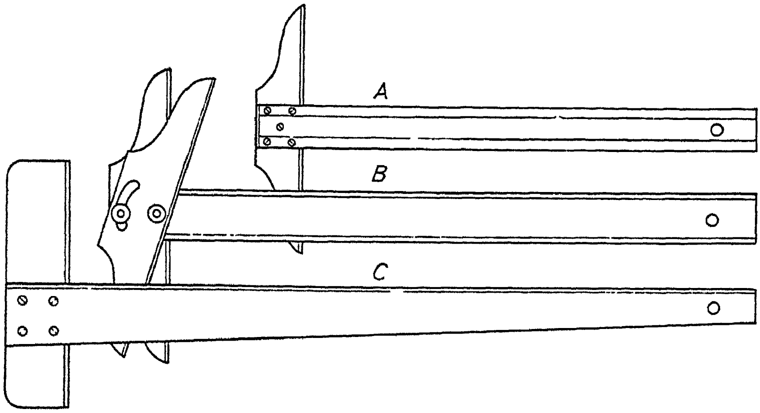


Fig. 8.—T-squares: fixed head, adjustable head and English forms.

The transparent-edge blade is much the best. A draftsman will have several fixed-head squares of different lengths and will find an adjustable-head square (*B*) of occasional use. The form shown at *C* is the English type with tapered blade and beveled edge. In a long square it has an advantage in balance and rigidity but has the objection that the lower edge is apt to disturb the draftsman's sense of perpendicularity. A T-square

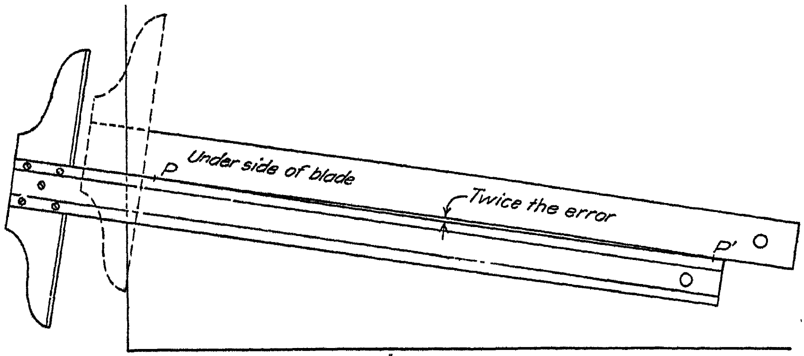


Fig. 9.—To test a T-square.

blade may be tested for straightness by drawing a sharp line through two points and then turning the square over and with the same edge drawing another line through the points, as shown in Fig. 9.

(4) **Triangles** made of transparent celluloid (fiberloid) are much to be preferred over wooden ones. Through internal strains they sometimes lose

their accuracy, so should be tested periodically by drawing perpendicular lines as shown in Fig. 10. For ordinary work a 6″ or 8″-45 degree and a 10″-60 degree are good sizes. Triangles should always be kept flat to prevent warping.

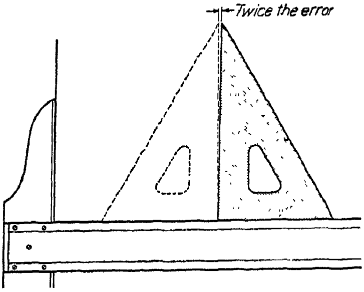


FIG. 10.—To test a triangle.

(5) **Scales.**—There are two general classes of scales, (1) those divided in decimals, with divisions of 10, 20, 30, 40, 50 and 60 to the inch, Fig. 11; and those divided in proportional feet and inches, Fig. 12. Trade names for these two types are apt to confuse beginning students, as the dealers call the first type "engineers' scales," and the second type "architects' scales"; whereas the first type is used only by civil engineers for plotting and map drawing, and in the graphic solution of problems, and not only architects but all engineers—mechanical, electrical,

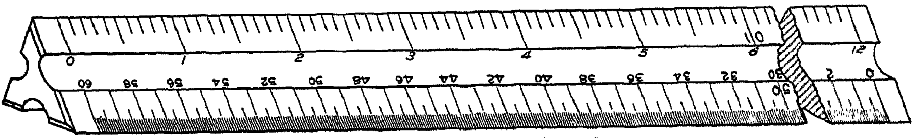


FIG. 11.—Civil engineers' scale.

industrial, chemical, mine, and civil—use the second type for all machine and structural drawings. Hence the captions on Figs. 11 and 12.

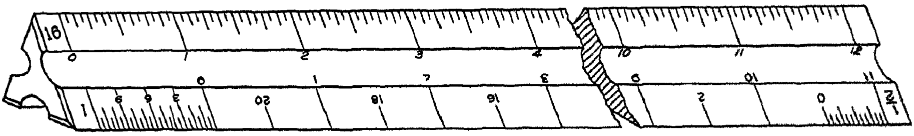


FIG. 12.—Mechanical engineers' or architects' scale.

Scales are usually made of boxwood, sometimes of metal or paper, and of shapes shown in section in Fig. 13. The triangular form, either *A* or *B*, is the commonest. Its only advantage is that it has more scales on one stick than the others, but this is offset by the delay in finding the scale wanted. Three flat scales are the equivalent of one triangular scale. The "opposite-bevel" scale *E* is easier to pick up than the regular form *D*. Many professional draftsmen use a set of six or eight scales, each graduated in one division only. A very popular scale among machine draftsmen at the present time is the new opposite-bevel "full-divided" flat scale with full size on one edge and half size on the other, Fig. 14, and a second with quarter size and eighth size.

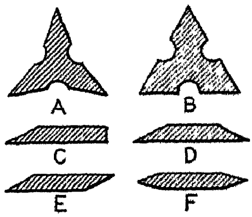


FIG. 13.—Scale sections.

(6) **Slide Rules.**—The slide rule, although not a drawing instrument, is essentially an engineer's instrument, and proficiency in its use is a requirement in every modern drafting room. A good way for a beginner to learn to use a slide rule is in connection with a drawing course. Its use facilitates the rapid calculation of volumes and weights of castings, an essential part of a draftsman's work. Of the several varieties of slide rules, those recom-

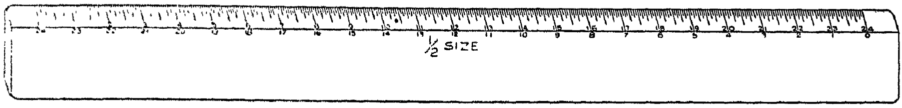


FIG. 14.—A full- and half-size scale.

mended for prospective engineers are a "Polyphase Duplex,"* a "Log Log Duplex"* or a "Log Log Trig,"* in 10-inch size.

(7) The best **thumbtacks** have thin heads with steel points screwed into them. Cheaper ones are made by stamping. Tacks with comparatively short tapering pins should be chosen. **Scotch drafting tape** is becoming more popular as a means of fastening paper to the drawing board. It may be used either by sticking a short piece across each corner or by taping the entire edge of the paper. There is a distinction between "drafting tape" and "masking tape" (made by the same company) in that the latter has a heavier coating of adhesive and does not come off the drawing paper so cleanly as the former.

(8) **Drawing pencils** are graded by letters from 6B (very soft and black), 5B, 4B, 3B, 2B, B, HB, F, H, 2H, 3H, 4H, 5H, 6H to 9H (extremely hard). Some draftsmen prefer a holder using standard-size drawing-lead fillers.

(9) A sandpaper **pencil pointer** or flat file should always be at hand for sharpening pencil and compass leads.

(10) The Ruby **pencil eraser** is the favorite at present. One of large size, with beveled end, is preferred. This eraser is much better for ink than a so-called ink eraser, as it will remove the ink perfectly without seriously damaging the surface of paper or cloth. A piece of Artgum or soft rubber is useful for cleaning paper.

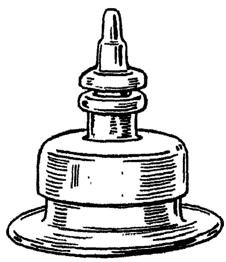


FIG. 15.—Bottle holder.

(11) **Drawing ink** is finely ground carbon in suspension, with shellac added to render it waterproof. The nonwaterproof ink flows more freely but smudges very easily. Chinese ink in stick form, rubbed up for use with water in a slate slab is used in making wash drawings and for very fine line work.

(12) **Bottleholders** prevent the possibility of ruining the drawing, table or floor by ink from an upset ink bottle. They are made in various patterns, one of which is illustrated in Fig. 15. As a temporary substitute the lower half of the paper container in which the ink was sold may be fastened to the

* Registered trade marks.

table with a thumbtack; or a strip of paper or cloth with a hole for the neck of the bottle may be tacked down over the bottle.

(13) The **penholder** should have a grip small enough to enter the mouth of a drawing ink bottle. An assortment of pens for lettering, grading from coarse to fine, may be chosen from those listed in Chap. IV. A **penwiper** of lintless cloth or thin chamois skin should always be at hand for both writing and ruling pens.

(14) **Curves.**—Curved rulers, called "irregular curves" or "French curves," are used for curved lines other than circle arcs. The patterns for

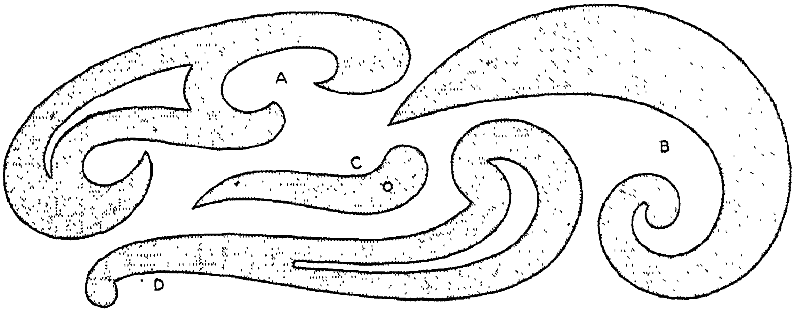


FIG. 16.—Irregular curves.

these curves are laid out in parts of ellipses and spirals or other mathematical curves in various combinations. For the student one ellipse curve of the general shape of Fig. 16*A* or *D*, and one spiral, either a log spiral *B* or one similar to the one used in Fig. 49, will be sufficient. (The curve of the logarithmic spiral is a closer approximation to the cycloid and other mathematical curves than any other simple curve.)

Splines are flexible curve rulers, which are adjusted to the points of the curve to be drawn and held in place by lead weights, called by the draftsmen "ducks." They come in various lengths and are part of the regular equipment of all aircraft drawing rooms. Fig. 17.

(15) **Drawing paper** is made in a variety of qualities with varying prices and may be had in either sheets or rolls. White drawing papers that will not turn yellow with age or exposure are used for finished drawings, maps, charts, and drawings for photographic reproduction. For working drawings, cream or buff detail papers are easier on the eyes than are white papers and are therefore preferred. In general, paper should have sufficient grain or "tooth" to take the pencil, should be agreeable to the eye, and should have a hard surface with good erasing qualities. Formerly, imported papers were considered superior to American-made products, but American mills are now making practically all the drawing paper used in this country. The cheap manila papers should be

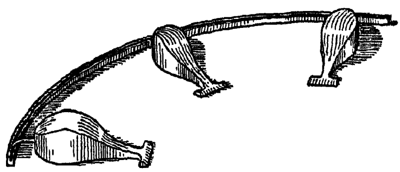


FIG. 17.—A spline.

avoided. A few cents more per yard is well spent in the increased comfort gained from working on good paper. In buying in quantity it is cheaper to buy roll paper by the pound.

(16) **Tracing papers** are thin papers, either *natural* or *transparentized,* through which drawings are traced, either in pencil or ink, and from which blueprints or similar contact prints can be made. In many drafting rooms, original drawings are being penciled on tracing papers and bond papers, and blueprints made directly from these drawings, a practice increasingly successful because of the improvements both in papers and in printing. Tracing cloth has been used for a great many years for making tracings in ink. Comparatively recently, pencil cloths have been developed on which pencil drawings can be made as easily as on paper. Tracing and duplicating processes are described in Chap. XXIX.

5. The instruments and materials described in this chapter are all that are needed in ordinary practice and are, as a rule, with the exception of such supplies as paper, pencils, ink, erasers, etc., what a draftsman is expected to take with him into a commercial drafting room.

There are many other special instruments and devices not necessary in ordinary work, but with which, nevertheless, the draftsman should be familiar, as they may be very convenient in some special cases and are often found as part of a drafting-room equipment. Some are described in Chap. XXX.

CHAPTER III

THE USE OF INSTRUMENTS

6. In beginning the use of drawing instruments, particular attention should be paid to correct method in their handling. Read carefully the instructions given and observe strictly all the details of the technique.

Facility will come with continued practice, but from the outset *good form* must be insisted upon. One might learn to write fairly, holding the pen between the fingers or gripped in the closed hand, but it would be poor form. Bad form in drawing is distressingly common and may be traced in every instance to lack of care or knowledge at the beginning, and the consequent formation of bad habits. These habits when once formed are most difficult to overcome.

All the mechanical drawing we do serves incidentally for practice in the use of instruments, but it is best for the beginner to make a few drawings solely to become familiar with the handling and "feel" of the instruments so that in working a drawing problem there may be no loss of time on account of faulty manipulation. Later the correct, skillful use of the instruments will become a subconscious habit.

The two requirements are *accuracy* and *speed*, and in commercial work neither is worth much without the other. Accurate penciling is the first consideration. Inking should not be attempted until real proficiency in penciling has been attained. A good instructor knows that it is mistaken kindness to the beginner to accept faulty or careless work. The standard held at the start will be carried through his professional life, and the beginner should learn that a *good* drawing can be made just as quickly as a *poor* one. Erasing is expensive and most of it can be avoided. The student allowed to continue in a careless way will grow to regard his erasers as the most important tools in his kit. The draftsman, of course, erases an occasional mistake, and instructions in making corrections should be given, but the beginner's sheets should be without blemish or inaccuracy.

7. Preparation for Drawing.—The drawing table should be set so that the light comes from the left, and adjusted to a convenient height for standing, that is, from 36 to 40 inches, with the board inclined at a slope of about 1 to 8. One may draw with more freedom standing than sitting. Wipe table and instruments with dustcloth before starting to draw.

8. The Pencil.—The grade of pencil must be selected carefully, with reference to the surface of the paper used. For a pencil layout on detail paper of good texture, a pencil as hard as 5H or 6H may be used, while for

finished pencil drawings or tracings on vellum, softer pencils (H to 3H) would have to be used to get printable lines. In every case the pencil chosen must be hard enough not to blur or smudge, but not so hard as to cut grooves in the paper under reasonable pressure. Sharpen the unlettered end to a long conical point by removing the wood with the penknife, as shown in Fig. 18*A*, and sharpening the lead as at *B* by rubbing it on the sandpaper pad. When drawing long lines with a conical point rotate the pencil so as to keep both line and pencil sharp. A flat or wedge point *C* will not wear away in use so fast as a conical point and on that account is preferred by some draftsmen for straight-line work. The long wedge point illustrated is made by first sharpening as at *A*, then making the two long cuts from opposite edges, as shown, flattening the lead on the file or sandpaper and finishing by touching the corners to make the wedge point narrower than the diameter of the lead.

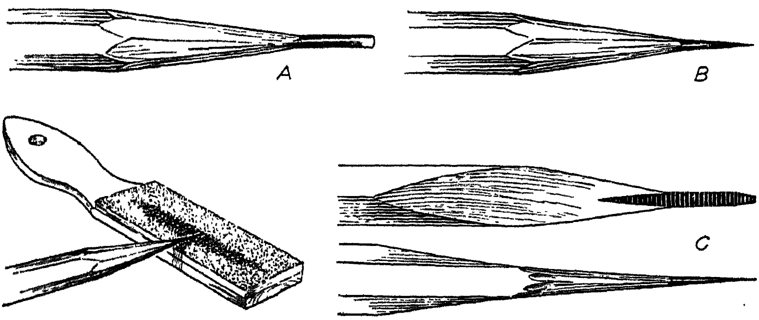


FIG. 18.—Sharpening the pencil.

A softer pencil (F or H) should be at hand for sketching and lettering. Have the sandpaper pad within easy reach and *keep the pencils sharp*. Some hang the pad or file on a cord attached to the drawing table. The professional draftsman sharpens his pencil every few minutes. Form the habit of sharpening the lead as often as you might dip a writing pen into the inkwell. All commercial and many college drafting rooms are equipped with Dexter or other pencil sharpeners, to save the draftsman's time.

Not only must pencil lines be clean and sharp, but, for pencil drawings and tracings to be blueprinted, it is absolutely necessary that all the lines of each kind be uniform, firm and opaque. This means a very careful choice of pencils. The attempt to make a firm line with too hard a pencil results in cutting deep grooves in the paper. Dust off excess graphite from the pencil drawing occasionally.

Too much emphasis cannot be given to the importance of clean, careful, accurate penciling. Never entertain the thought that poor penciling may be corrected in tracing.

9. Use of the T-square.—The T-square is always used with its head on the left edge of the drawing board. (An exception to this is made in the

case of a left-handed person; for him the table should be placed with the light coming from the right and the T-square used on the right edge.)

Since the T-square blade is more rigid near the head than toward the outer end, the paper, if much smaller than the size of the board, should be placed close to the left edge of the board (within an inch or so) with its lower edge several inches from the bottom. With the T-square against the left edge of the board, square the top of the paper approximately; hold in this position, slipping the T-square down from the edge, and put a thumbtack in each upper corner, pushing it in up to the head so that the head aids in holding the paper; move the T-square down over the paper to smooth out possible wrinkles and put thumbtacks in the other two corners.

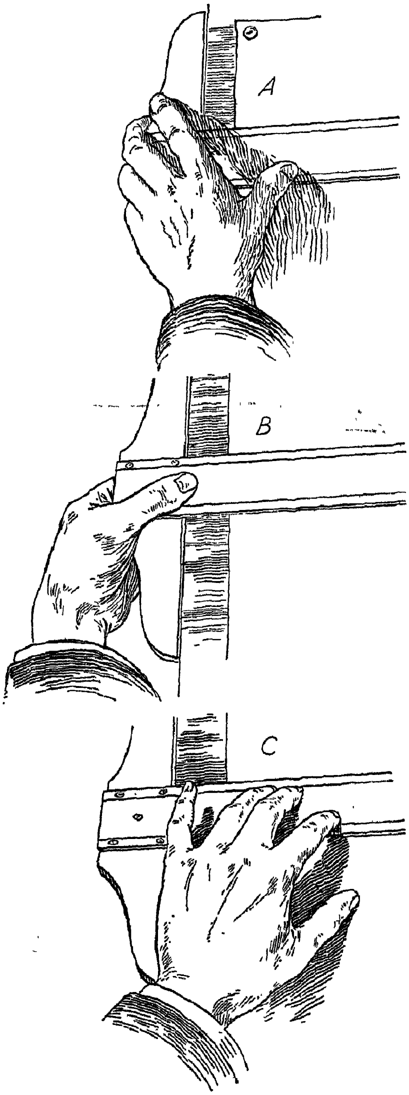


Fig. 19.—Manipulating the T-square.

Manifestly the T-square is used for drawing horizontal lines. These lines should always be drawn from left to right; consequently points for their location should be marked on the left side; vertical lines are drawn with the triangle set against the T-square, always with the perpendicular edge nearest the head of the square and thus toward the light. These lines are always drawn upward, from bottom to top; consequently their location points should be at the bottom.

In drawing lines, great care must be exercised to keep them accurately parallel to the guiding edge of the T-square or triangle, holding the pencil point lightly, but close against the edge, and not varying the angle during the progress of the line.

For drawing horizontal lines the T-square is manipulated as follows: Holding the head of the tool as shown at A, Fig. 19, the draftsman slides it along the edge of the board to a position very near the position desired. Then for closer adjustment he changes his hold either to that shown at B, in which the thumb remains on top of the T-square head and the other fingers

press against the underside of the board; or, more often, to that shown at *C*, in which the fingers remain on the square and the thumb is placed on the board.

In drawing vertical lines the T-square is held in position against the left edge of the board by the thumb and little finger of the left hand while the other fingers of this hand adjust the triangle, as illustrated in Fig. 20. One may be sure that the T-square is in contact with the board by hearing the little double click as the two come together.

10. Laying Out the Sheet.—The paper is usually cut somewhat larger than the desired size of the drawing and is trimmed to size after the work is

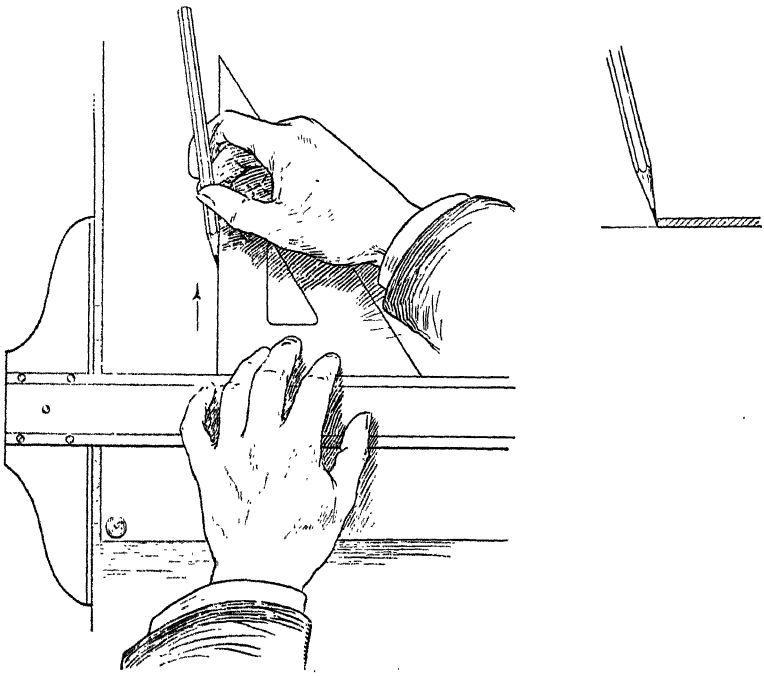


Fig. 20.—Drawing a vertical line.

finished. Suppose the finished size is to be 11″ × 17″ with a ½″ border inside. Lay the scale down on the paper close to the lower edge and measure 17″, marking the distance with the pencil; at the same time mark ½″ inside at each end for the border line. Use a short dash forming a continuation of the division line on the scale in laying off a dimension. Do not bore a hole with the pencil. Near the left edge mark 11″ and ½″ border-line points. Through these four marks on the left edge draw horizontal lines with the T-square, and through the points on the lower edge draw vertical lines, using the triangle against the T-square.

11. Use of the Triangles.—We have seen that the vertical lines are drawn with the triangle set against the T-square, Fig. 20. In both penciling

and inking, the triangles should always be used in contact with a guiding straightedge. To ensure accuracy never work to the extreme corner of a triangle; to avoid having to do so, keep the T-square below the base line.

With the T-square against the edge of the board, lines at 30, 45, and 60 degrees may be drawn as shown in Fig. 21, the arrows indicating the

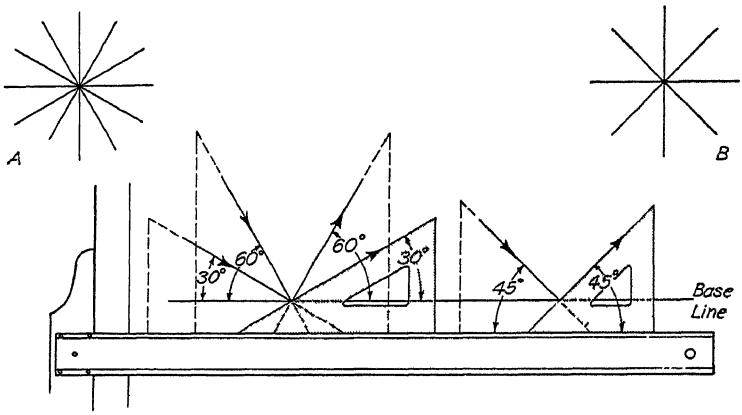


Fig. 21.—To draw angles of 30°, 45° and 60°.

direction. The two triangles are used in combination for angles of 15, 75, 105 degrees, etc., Fig. 22. Thus any multiple of 15 degrees can be drawn directly, and a circle can be divided with the 45-degree triangle into 4 or 8 parts, with the 60-degree triangle into 6 or 12 parts and with both into 24 parts.

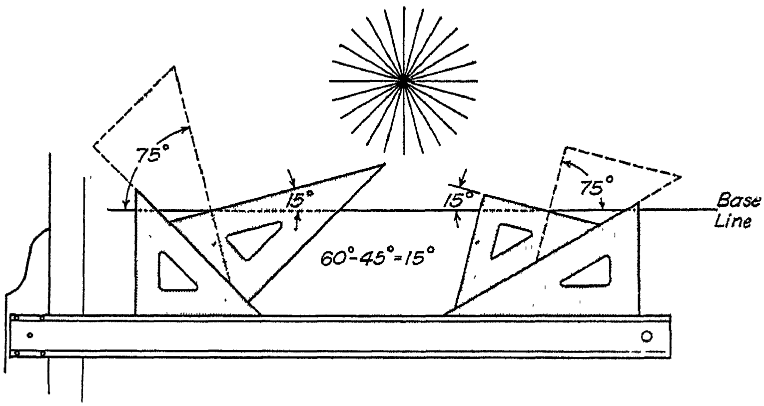


Fig. 22.—To draw angles of 15° and 75°.

In using the triangles always keep the T-square at least ½ inch below the starting line.

To draw one line parallel to another, Fig. 23, adjust, to the given line, a triangle held against a straightedge (T-square or triangle); hold the guiding edge in position and slip the triangle on it to the required position.

To draw a perpendicular to any line, Fig. 24*A*, fit the hypotenuse of a triangle to it, with one edge against the T-square or another triangle; hold the T-square in position and turn the triangle until its other side is against the edge; the hypotenuse will then be perpendicular to the line. Move it to the required position. *Or* a quicker method is to set the triangle with the hypotenuse against the guiding edge, fit one side to the line, slide the triangle to the required point and draw the perpendicular, as shown at *B*.

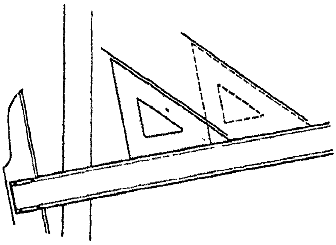


Fig. 23.—To draw parallel lines.

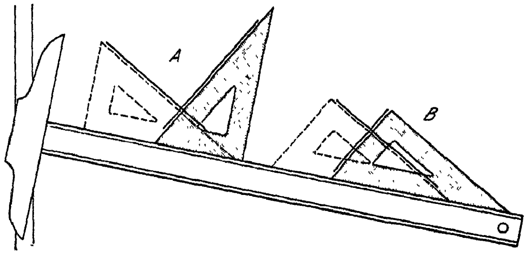


Fig. 24.—To draw perpendicular lines.

Never attempt to draw a perpendicular to a line by placing one leg of the triangle along the line.

12. Use of the Dividers.—The dividers are used for transferring measurements and for dividing lines into any number of equal parts. Facility in the use of this instrument is most essential, and quick and absolute control of its manipulation must be gained. It should be opened with one hand by pinching the chamfer with the thumb and second finger. This will throw it into correct position with the thumb and forefinger outside of the legs and the second and third fingers inside, with the head resting just above the second joint of the forefinger, Fig. 25. It is thus under perfect control, with the thumb and forefinger to close it and the other two to open it. This motion should be practiced until an adjustment to the smallest fraction can be made. In coming down to small divisions the second and third fingers must be gradually slipped out from between the legs while they are closed down upon them. Notice that the little finger is not used in manipulating the dividers.

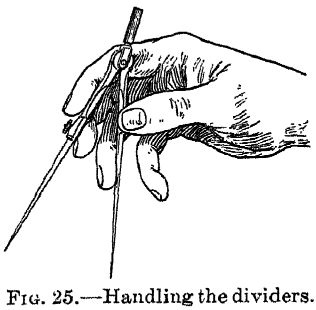


Fig. 25.—Handling the dividers.

13. To Divide a Line by Trial.—In bisecting a line the dividers are opened roughly at a guess to one-half the length. This distance is stepped off on the line, holding the instrument by the handle with the thumb and forefinger. If the division is short the leg should be thrown out to one-half the remainder, estimated by the eye, without removing the other leg from

the paper, and the line spaced again with this new setting, Fig. 26. If the result should not come out exactly, the operation may be repeated. With a little experience a line may be divided very rapidly in this way. Similarly, a line, either straight or curved, may be divided into any number of equal parts, say five, by estimating the first division, stepping this lightly along the line, with the dividers held vertically by the handle, turning the instrument first in one direction and then in the other. If the last division falls short, one-fifth of the remainder should be added by opening the dividers, keeping the one point on the paper. If the last division is over, one-fifth of the excess should be taken off and the line respaced. If it is found difficult to make this small adjustment accurately with the fingers, the hairspring may be used. It will be found more convenient to use the bow spacers instead of the dividers for small or numerous divisions. Avoid pricking unsightly holes in the paper. The position of a small prick point may be preserved if necessary by drawing a small circle around it with the pencil. For most work and until one is very proficient it is best to divide a line into a number of parts with the scale as explained on page 61.

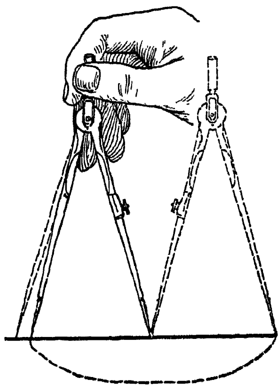


FIG. 26.—Bisecting a line.

Proportional dividers, Fig. 1029, are sometimes used to divide both straight lines and circles.

14. Use of the Compasses.—The compasses have the same general shape as the dividers and are manipulated in a similar way. First of all the needle should be permanently adjusted. Insert the pen in place of the pencil leg, turn the needle with the shoulder point out and set it a trifle longer than the pen, Fig. 27, replace the pencil leg, sharpen the lead to a long bevel, as in Fig. 28, and adjust it to the needle point.

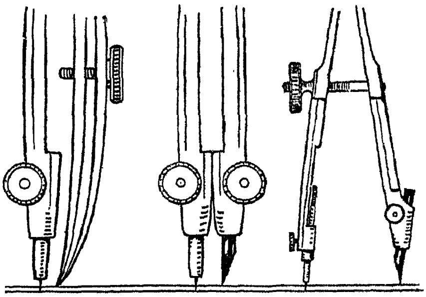


FIG. 27. FIG. 28.

To draw a circle, measure and mark the radius on the paper, place the needle point at the center, guiding it with the left hand, Fig. 29, and adjust the pencil to the radius, setting the compasses with one hand as in Fig. 25.

When the lead is adjusted to pass exactly through the mark, raise the right hand to the handle and draw the circle clockwise in one sweep, rolling the handle with the thumb and forefinger, and inclining the compasses slightly in the direction of the line, Fig. 30.

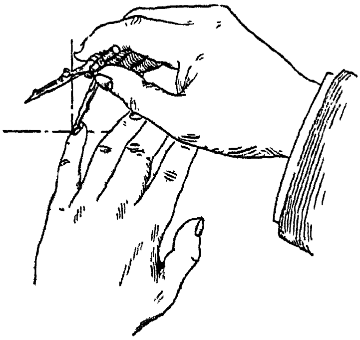


FIG. 29.—Guiding the needle point.

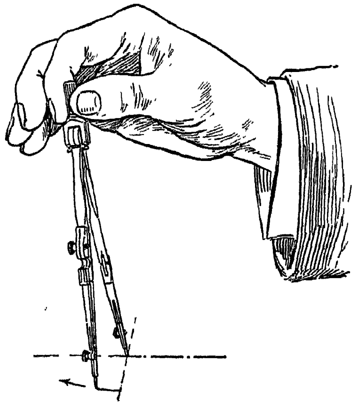


FIG. 30.—Starting a circle.

The position of the fingers after the revolution is illustrated in Fig. 31. The pencil line may be brightened if necessary by going back over it in the reverse direction (this is one exception to a caution at the end of the chapter). Circles up to perhaps three inches in diameter may be drawn with the legs

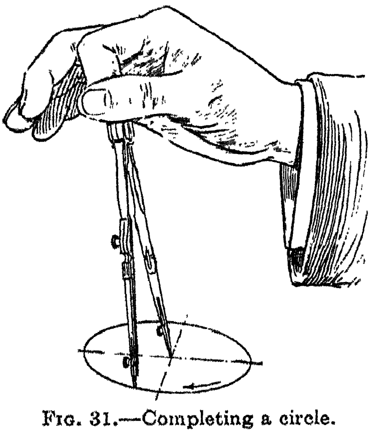


FIG. 31.—Completing a circle.

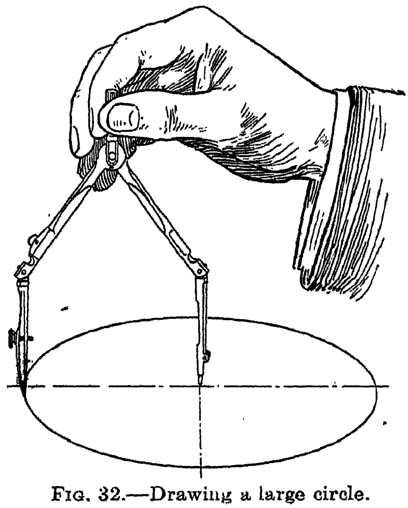


FIG. 32.—Drawing a large circle.

of the compasses straight, but for larger sizes both the needle-point leg and the pencil or pen leg should be bent at the knuckle joints so as to be perpendicular to the paper, Fig. 32. The 6-inch compasses may be used in this way for circles up to perhaps ten inches in diameter; larger circles are made

by using the lengthening bar, as illustrated in Fig. 33, or by using the beam compasses, Fig. 7. In drawing concentric circles the *smallest* should always be drawn *first*, before the center hole has become worn.

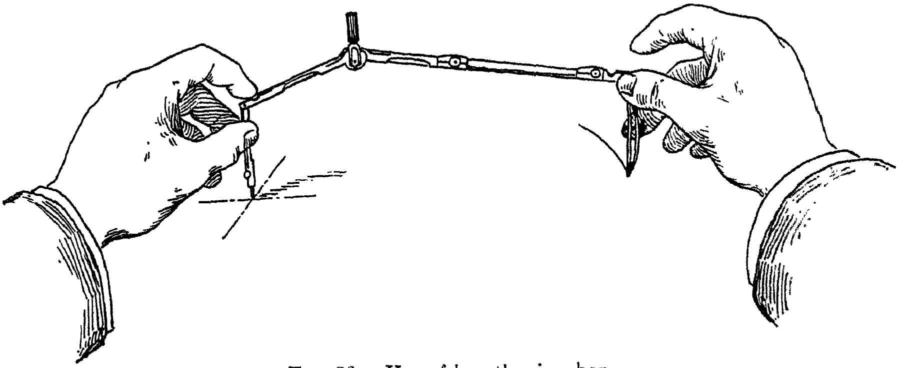


FIG. 33.—Use of lengthening bar.

The **bow instruments** are used for small circles, particularly when a number are to be made of the same diameter. To avoid wear and ultimate stripping of the thread, the pressure of the spring against the nut should be relieved in changing the setting by holding the points in the left hand and spinning the nut in or out with the finger. Small adjustments should be made with one hand, with the needle point in position on the paper, Fig. 34.

15. Use of the Scale.—In representing objects that are larger than can be drawn to their natural or full size it is necessary to reduce the size of the drawing in some regular proportion, and for this purpose the mechanical engineer's (or architect's) scales are used. The first reduction is to what is commonly called "half size," or, correctly speaking, to the scale of 6″ = 1 ft. This scale is used on working drawings even if the object is only slightly larger than could be drawn full size. If the draftman hasn't a half-size scale (see Fig. 14) he should use the full-size scale, considering 6 inches on the scale to represent 1 foot. Thus the half-inch divisions become full inches, each of which is divided into eighths. (Do *not* use the scale of ½″ = 1 ft. for half-size drawings.)

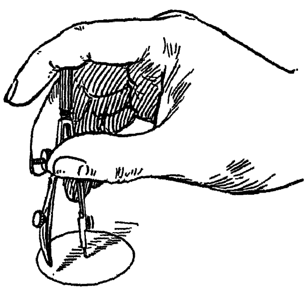


FIG. 34.—Adjusting the bow pen.

If this reduction is too large for the paper the drawing is made to the scale of 3″ = 1 ft., often called "quarter size"; that is, 3 inches measured on the drawing is equal to 1 foot on the object. This is the first reduction scale of the usual triangular scale; on it the distance of 3 inches is divided into 12 equal parts, and each of these is subdivided into eighths. This distance should be thought of not as 3 inches but as a foot divided into inches and eighths of an inch. Notice that the divisions start with the zero

on the inside, the inches of the divided foot running to the left and the open divisions of feet to the right, so that dimensions given in feet and inches may be read directly, as 1′-0½″, Fig. 35. On the other end will be found the scale of 1½″ = 1 ft., or eighth size, with the distance of 1½ inches divided on the right of the zero into 12 parts and subdivided into quarter inches, with the foot divisions to the left of the zero coinciding with the marks of the 3″ scale.

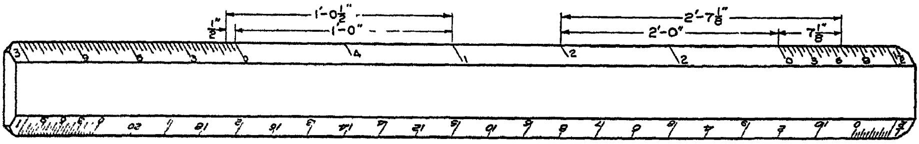


Fig. 35.—Reading the scale.

If the 1½″ scale is too large for the object, the next smaller size is the scale 1″ = 1 ft. and so on down as shown in the following table:

Scales

24″	= 1′-0″ (double size)	¾″	= 1′-0″ (1/16 size)
12″	= 1′-0″ (full size)	½″	= 1′-0″ (1/24 size)
6″	= 1′-0″ (½ size)	⅜″	= 1′-0″ (1/32 size)
4″	= 1′-0″ (⅓ size) rarely used	¼″	= 1′-0″ (1/48 size)
3″	= 1′-0″ (¼ size)	3/16″	= 1′-0″ (1/64 size)
2″	= 1′-0″ (⅙ size) rarely used	⅛″	= 1′-0″ (1/96 size)
1½″	= 1′-0″ (⅛ size)	3/32″	= 1′-0″ (1/128 size)
1″	= 1′-0″ (1/12 size)		

16. In stating the scale used on a drawing the first figure should always refer to the drawing and the second to the object. Thus "Scale 3″ = 1′-0″" means that 3 inches on the drawing is equal to 1 foot on the object.

Drawings to odd proportions such as 9″ = 1 ft., 4″ = 1 ft., etc., are used only in rare cases when it is desired to make it difficult or impossible for a workman to measure them with an ordinary rule.

The scale ¼″ = 1′-0″ is the usual one for ordinary house plans and is often called by architects "quarter scale." This term should not be confused with the term "quarter size," as the former means ¼ inch to 1 foot and the latter ¼ inch to 1 inch.

The size of a circle is generally stated by giving its diameter, while to draw it the radius is necessary. In drawing to half size it is thus often convenient to lay off the amount of the diameter with a quarter-size scale and use this distance as the radius.

As far as possible, successive measurements on the same line should be made without shifting the scale.

Small pieces are often made "double size," and very small mechanisms, such as drawings of watch parts, are drawn to greatly enlarged sizes: 10 to 1, 20 to 1, 40 to 1; and 50 to 1, using special enlarging scales.

For plotting and map drawing the civil engineer's scale of decimal parts, with 10, 20, 30, 40, 50, 60 or sometimes 20, 30, 40, 50, 60, 80 divisions to the inch, is used. This scale is not used for machine or structural work but is used in certain aircraft drawings.

The important thing in drawing to scale is to think of and speak of each dimension in its full size and not in the reduced (or enlarged) size it happens to be on the paper.

17. The Ruling Pen.—The ruling pen is for inking straight lines and noncircular curves. Several types are illustrated in Fig. 5. The important feature is the shape of the blades; they should have a well-designed ink space between them, and their points should be rounded (actually elliptical in form) equally, as in Fig. 36. If pointed, as in Fig. 37, the ink will arch up as shown and will be provokingly hard to start. If rounded to a blunt point

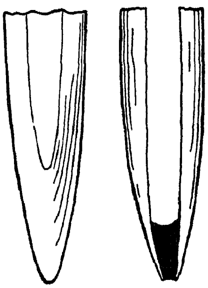


Fig. 36.
Correct.

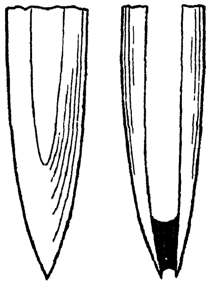


Fig. 37.

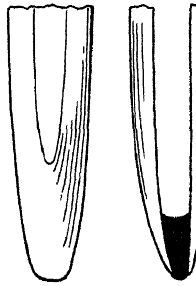


Fig. 38.

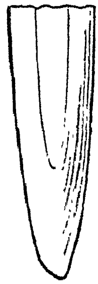


Fig. 39.

Incorrect shapes of ruling pen points.

as in Fig. 38, the ink will flow too freely, the result being bulbs and overruns at the ends of the lines. Pens in constant use become dull and worn like Fig. 39. It is easy to tell whether or not a pen is dull by looking for the reflection of light that travels from the side and over the end of the point when the pen is turned in the hand. If the reflection can be seen all the way the pen is too dull. A pen in poor condition is an abomination, but a well-sharpened one is a delight to use. Every draftsman should be able to keep his pens in fine condition.

18. To Sharpen a Pen.—The best stone for the purpose is a hard Arkansas knife piece, used dry. It is well to soak a new stone in oil for several days before using. The ordinary carpenter's oilstone is too coarse for drawing instruments.

The nibs must first be brought to the correct shape, as in Fig. 36: screw them together until they touch and, holding the pen as in drawing a line, draw it back and forth on the stone, starting the stroke with the handle at 30° or less with the stone, and swinging it up past the perpendicular as the line across the stone progresses. This will bring the nibs to exactly the same shape and length, leaving them very dull. Then open them slightly and sharpen each blade in turn, *on the outside only,* until the bright spot on the

end has just disappeared, holding the pen now as in Fig. 40 at a small angle with the stone and rubbing it back and forth with a slight oscillating or rocking motion to conform to the shape of the blade. A stone three or four inches long held in the left hand with the thumb and fingers gives better control than one laid on the table. Some prefer to hold the stone in the right hand with its face perpendicular to the forearm and move it back and forth with a short wrist motion, holding the pen against it with the other hand. The pen should be examined frequently and the operation stopped just when the reflecting spot has vanished. A pocket magnifying glass may be of aid in examining the points. The blades should not be sharp enough to cut the paper when tested by drawing a line, without ink, across it. If oversharpened, the blades should again be brought to touch and a line swung very lightly across the stone as in the first operation. When tested with

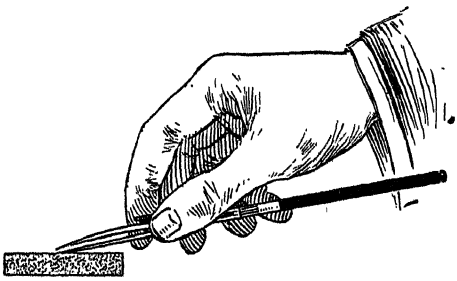


Fig. 40.—Sharpening a pen.

ink the pen should be capable of drawing clean sharp lines down to the finest hairline. If these finest lines are ragged or broken the pen is not perfectly sharpened. It should not be necessary to touch the inside of the blades unless a burr has been formed, which might occur if the metal is very soft, or the stone too coarse, or the pressure too heavy. To remove such a burr or wire edge draw a strip of detail paper between the nibs or open the pen wide and lay the entire inner surface of the blade flat on the stone and move it with a very light touch.

The beginner had best practice by sharpening several old pens before attempting to sharpen a good instrument. After using, the stone should be wiped clean and a drop of oil rubbed over it.

19. Use of the Ruling Pen.—The ruling pen is always used in connection with a guiding edge—T-square, triangle, straightedge or curve. The T-square and triangle should be held in the same positions as for penciling. In inking it is bad practice to use only a triangle with the pen.

To fill the pen take it to the bottle and touch the quill filler between the nibs, being careful not to get any ink on the outside of the blades. Not more than $\frac{3}{16}$ to $\frac{1}{4}$ inch of ink should be put in, or the weight of the ink will cause it to drop out in a blot. The pen should be held in the finger tips

as illustrated in Fig. 41, with the thumb and second finger in such position that they may be used in turning the adjusting screw, and the handle resting on the forefinger. This hold should be observed carefully, as the tendency will be to bend the second finger to the position in which a pencil or writing pen is held, a position obviously convenient in writing, in order to facilitate

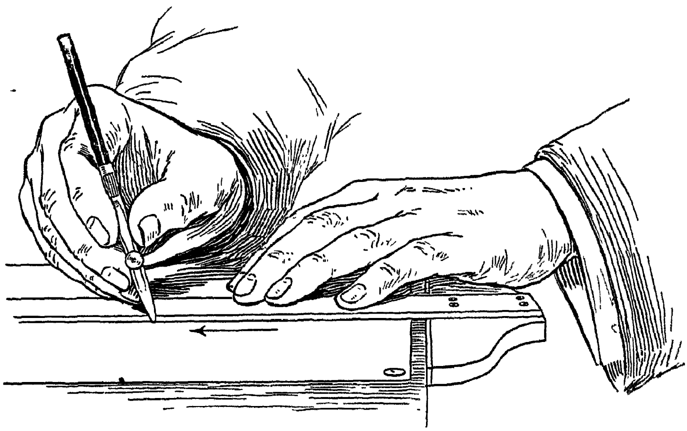


FIG. 41.—Correct position of ruling pen.

the upstroke, but since this upstroke is not required with the ruling pen the position illustrated is preferable.

For full lines the screw should be adjusted to give a strong line of the size of the first line of Fig. 46. A fine drawing does not mean a drawing with fine lines, but one with uniform lines and accurate connections.

20. The pen should be held against the straightedge, with the blades parallel to it, the screw being on the outside and the handle inclined slightly to the right and always kept in a plane passing through the line and perpendicular to the paper. The pen is thus guided by the upper edge of the ruler, whose distance from the pencil line will therefore vary with the thickness of the ruler and with the shape of the under-blade of the pen, as illustrated in actual size in Fig. 42. If the pen point is thrown out from the perpendicular it will run on one blade and a line ragged on one side will result. If turned in from the perpendicular the ink is very apt to run under the edge of the ruler and cause a blot.

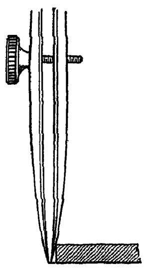


FIG. 42.

A line is drawn with a whole-arm movement, the tips of the third and fourth fingers resting on and sliding along the straightedge and keeping the angle of inclination constant. Just before the end of the line is reached, the two guiding fingers on the straightedge should be stopped, and, without stopping the motion of the pen, the line finished with a finger movement. Short lines are drawn with this finger movement alone. When the end

of the line is reached lift the pen quickly and move the straightedge away from the line. The pressure on the paper should be light, but sufficient to give a clean-cut line, and will vary with the kind of paper and the sharpness of the pen, but the pressure against the T-square should be only enough to guide the direction.

If the ink refuses to flow it is because it has dried and clogged in the extreme point of the pen. If pinching the blades slightly or touching the pen on the finger does not start it, the pen should immediately be wiped out and fresh ink supplied. Pens must be wiped clean after using, or the ink will corrode the steel and finally destroy them.

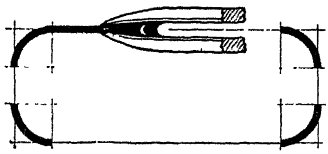


FIG. 43.—Inking a pencil line.

In inking on either paper or cloth the full lines will be much wider than the pencil lines, and thus the beginner must be very careful to have the center of the ink line cover the pencil line, as shown in Fig. 43.

Instructions in regard to the ruling pen apply also to the compasses. The instrument should be slightly inclined in the direction of the line and both nibs of the pen kept on the paper, bending the knuckle joints, if necessary, to effect this.

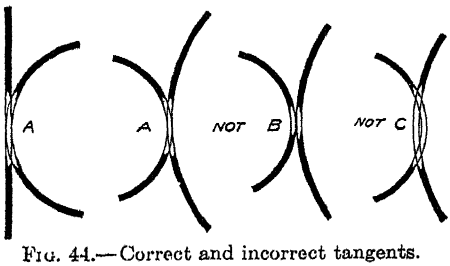


FIG. 44.—Correct and incorrect tangents.

It is a universal rule in inking that *circles and circle arcs must be inked first.* It is much easier to connect a straight line to a curve than a curve to a straight line.

21. Tangents.—It should be noted particularly that two lines are tangent to each other when the center lines of the lines are tangent and not when the lines simply touch each other; thus at the point of tangency the width will be equal to the width of a single line, Fig. 44. Before inking tangent lines the point of tangency should be marked in pencil. For an arc tangent to a straight line this point will be on a line through the center

of the arc and perpendicular to the straight line, and for two circle arcs will be on the line joining their centers. See paragraphs 62 to 69.

After reading these paragraphs the beginner had best take a blank sheet of paper and cover it with ink lines of varying lengths and weights, practicing starting and stopping on penciled limits, until he feels acquainted with the pens. If in his set there are two pens of different sizes the larger one should be used, as it fits the hand of the average man better than the smaller one, holds more ink and will do just as fine work. High-grade pens usually come from the makers well sharpened. Cheaper ones often need sharpening before they can be used.

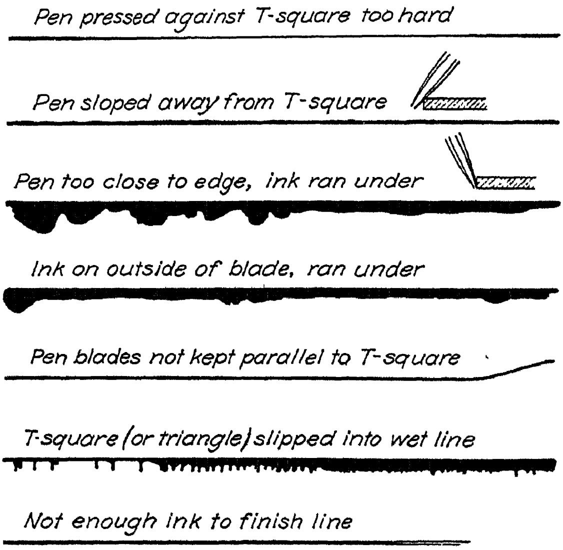


FIG. 45.—Faulty lines.

22. Faulty Lines.—If inked lines appear imperfect in any way the reason should be ascertained immediately. It may be the fault of the pen, the ink, the paper or the draftsman, but with the probabilities greatly in favor of the last.

Figure 45 illustrates the characteristic appearance of several kinds of faulty lines. The correction in each case will suggest itself.

23. The Alphabet of Lines.—As the basis of drawing is the line, a set of conventional symbols covering all the lines needed for different purposes may properly be called an "alphabet of lines." Figure 46 shows the alphabet of lines adopted by the American Standards Association (ASA), as applied:

1. To layout drawings in pencil on detail paper to be traced on tracing paper or cloth.
2. To drawings either made directly or traced in pencil on tracing paper or pencil cloth, from which blueprints or other reproductions are to be made.

3. To tracing in ink on tracing cloth or tracing paper; and to inked drawings on white paper for display or photo-reproductions.

The ASA recommends three weights of lines: heavy, medium and light, for finished drawings, "both for legibility and appearance," but says that "for rapid practice this may be simplified to two weights: *medium* for out-

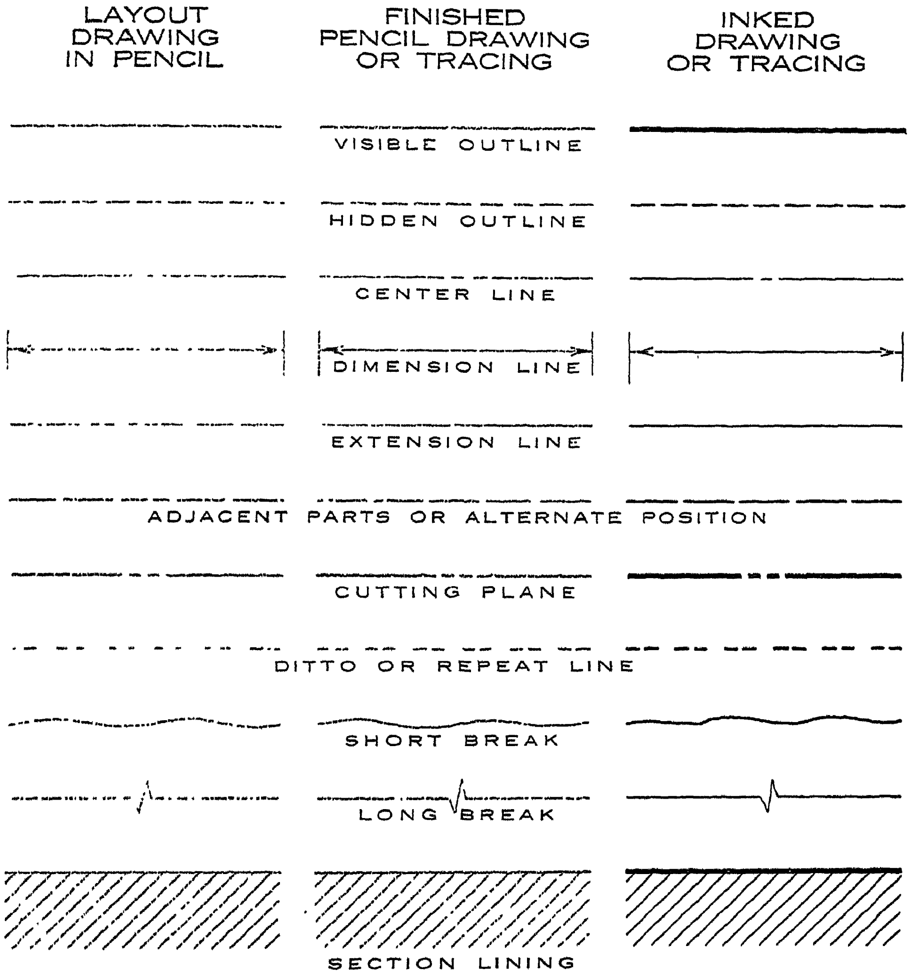


FIG. 46.—The alphabet of lines.

lines, hidden, cutting-plane, short-break, adjacent-part and alternate-position lines, and *light* for section, center, extension, dimension, long-break and ditto lines." The actual widths of the three weights of lines, on average drawings, should be about as given in Fig. 46. A convenient line gage

designed by Dr. C. V. Mann is illustrated in Fig. 47. If applied to Fig. 46 this gage would show the heavy lines in ink to be between $\frac{1}{40}$ and $\frac{1}{50}$ of an inch, the medium lines $\frac{1}{80}$ of an inch and the fine lines $\frac{1}{200}$ of an inch in width. Figure 48 shows the application of the alphabet of lines.

24. Use of the French Curve.—The French curve, as has been stated on page 10, is a ruler for noncircular curves. When sufficient points have been determined it is best to sketch in the line lightly in pencil, freehand, without losing the points, until it is clean, smooth, continuous, and satisfactory to the eye. The curve should then be applied to it, selecting a part that will fit a portion of the line most nearly and seeing to it particularly that the curve is so placed that the direction in which its curvature increases is the direction in which the curvature of the line increases. See Fig. 49. In drawing that part of the line matched by the curve, *always* stop a little short of the distance in which the ruler and the line seem to coincide. After drawing this portion the curve is shifted to find another place that will coincide with the continuation of the line. In shifting the curve care should be taken to preserve smoothness and continuity and to avoid breaks or cusps. This may be done if in its successive positions the curve is always adjusted so that it coincides for a short distance with the part of the line already drawn. Thus at each juncture the tangents will coincide.

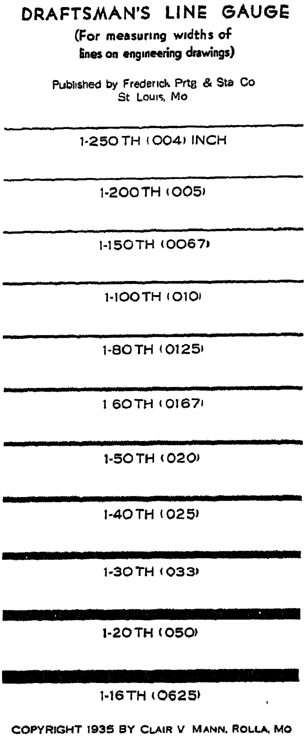


FIG. 47.—Mann's line gage.

If the curved line is symmetrical about an axis, marks locating this axis, after it has been matched accurately on one side, may be made in pencil on the curve and the curve then reversed. In such a case exceptional care must be taken to avoid a "hump" at the joint. It is often better to stop a line short of the axis on each side and close the gap afterward with another setting of the curve.

When using the curve in inking, the pen should be held perpendicular and the blades kept parallel to the edge. Inking curves will be found to be excellent practice.

Sometimes, particularly at sharp turns, a combination of circle arcs and curve may be used; in inking, for example, a long narrow ellipse the sharp curves may be inked by selecting a center on the major axis by trial, drawing as much of an arc as will practically coincide with the ends of the ellipse, and then finishing the ellipse with the curve. The experienced

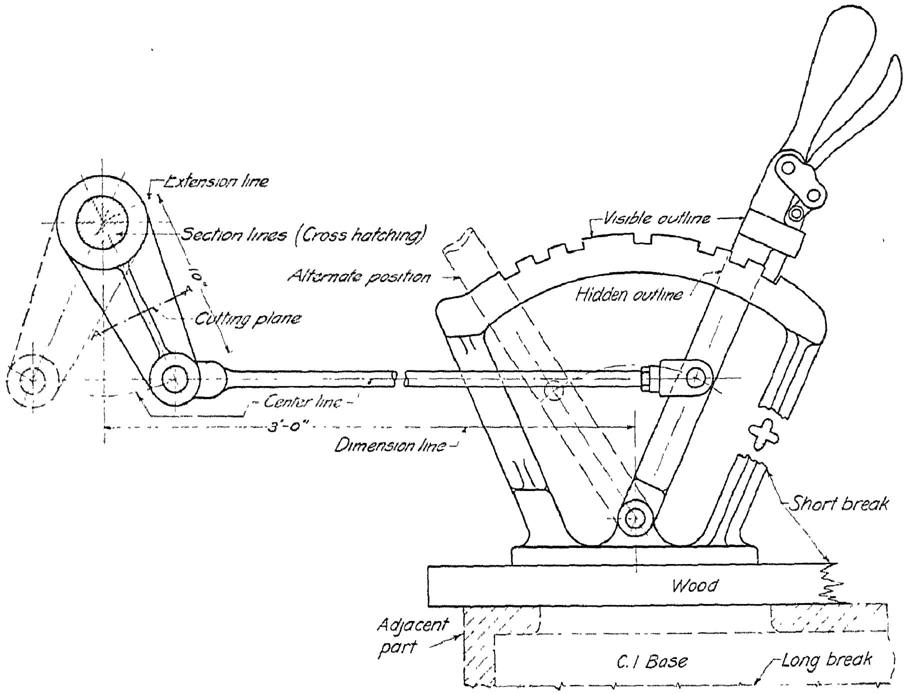


FIG. 48.—The alphabet illustrated.

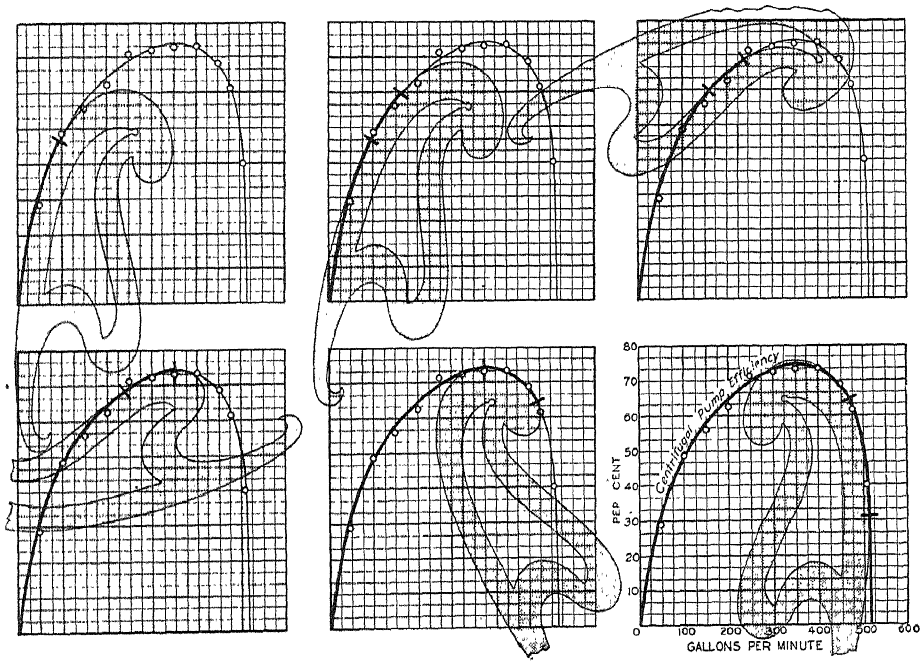


FIG. 49.—Use of the French curve.

draftsman will sometimes ink a curve that cannot be matched accurately, by varying the distance of the pen point from the ruling edge as the line progresses, but the beginner should not attempt it.

Splines are commonly used for drawing curves in aircraft and automotive work, and some experience is needed to handle them with facility. Select a spline long enough to cover the full length of the curve and adjust it to position with a sufficient number of lead weights (ducks), always keeping the ducks normal to the curve. See Fig. 17.

25. Erasing.—The technique of erasing both pencil lines and ink lines is a necessary item to learn. A designer, working freely but lightly, uses a soft pencil eraser when changing some detail, so as not to damage the finish of the paper. Heavier lines are best removed with a Ruby pencil eraser. If the paper has been grooved by the line it may be rubbed over with a burnisher, or even with the back of the thumb nail. In erasing an ink line hold the paper down firmly and, with a Ruby pencil eraser, rub lightly and patiently, first along the line, then across it, until the ink is removed. A triangle slipped under the paper or cloth gives a good backing surface. When an erasure is to be made close to other lines, select an opening of the best shape on the erasing shield and rub through it, holding the shield down firmly, first seeing that both of its sides are clean. Wipe off the eraser crumbs from the paper with a dustcloth or brush. Never scratch out a line or a blot with a knife or razor blade, and use so-called ink erasers very sparingly if at all. A skilled draftsman sometimes uses a sharp blade to trim a thickened spot or overrunning end on a line. For extensive erasing an electric erasing machine is a great convenience. Several successful models are on the market.

26. Special Instruments.—Various instruments, such as drafting machines, parallel rules, pantographs, lettering machines, proportional dividers, etc., not in the usual draftsman's outfit, are used in commercial drafting work. A description of a number of these special instruments is given in Chap. XXX.

27. Exercises in the Use of Instruments.—The following may be used as progressive exercises for practice in using the instruments, doing them either as finished pencil drawings, or in pencil layout to be inked. Line work should conform to that given in the alphabet of lines, Fig. 46. Sheet layouts on American Standard sizes will be found in the Appendix.

The problems in Chap. V afford excellent additional practice in accurate penciling.

(1) **An Exercise for the T-square, Triangle and Scale.**—Fig. 50. Through the center of the space draw a horizontal and a vertical line. Measuring on these lines as diameters lay off a 4″ square. Along the lower side and upper half of the left side measure ½″ spaces with the scale. Draw all horizontal lines with the T-square and all vertical lines with the T-square and triangle.

(2) **An Interlacement.**—Fig. 51. For T-square, triangle and dividers. Draw a 4″ square. Divide left side and lower side into seven equal parts with dividers. Draw horizontal and vertical lines across the square through these points. Erase the parts not needed.

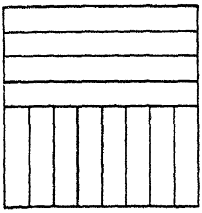


Fig. 50.

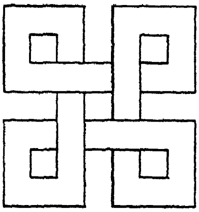


Fig. 51.

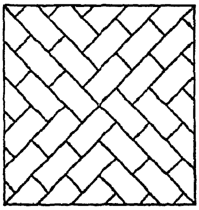


Fig. 52.

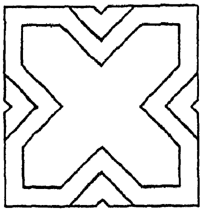


Fig. 53.

(3) **A Street-paving Intersection.**—Fig. 52. For 45° triangle and scale. An exercise in starting and stopping short lines. Draw a 4″ square. Draw its diagonals with 45° triangle. With the scale, lay off ½″ spaces along the diagonals, from their intersection. With 45° triangle, complete figure, finishing one quarter at a time.

(4) **A Square Pattern.**—Fig. 53 For 45° triangle, dividers and scale. Draw a 4″ square and divide its sides into three equal parts with dividers. With 45° triangle, draw diagonal lines connecting these points. Measure ⅜″ on each side of these lines and finish the pattern as shown.

(5) **Five Cards.**—Fig. 54. Visible and hidden lines. Five cards 1¾″ × 3″ are arranged with the bottom card in the center, the other four overlapping each other and placed so that their outside edges form a 4″ square. Hidden lines indicate edges covered.

(6) **Concentric Circles.**—Fig. 55. For compasses (legs straight) and scale. Draw a horizontal line through center of space. On it mark off radii for eight concentric circles, ¼″ apart. In drawing concentric circles always draw the smallest first.

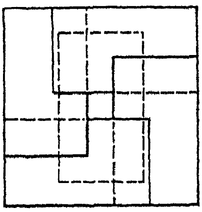


Fig. 54.

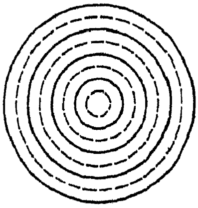


Fig. 55.

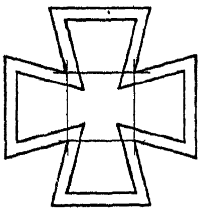


Fig. 56.

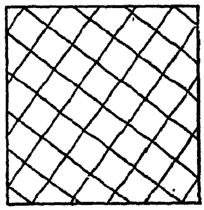


Fig. 57.

(7) **A Maltese Cross.**—Fig. 56. For T-square, spacers and both triangles. Draw a 4″ square and a 1⅜″ square. From the corners of inner square draw lines to outer square at 15° and 75°, with the two triangles in combination. Mark points with spacers ¼″ inside each line of this outside cross, and complete figure with triangles in combination.

(8) **A Screen.**—Fig. 57. Two systems of parallel lines perpendicular to each other. Draw a 4″ square. Locate a point ½″ to the right of the lower left corner and another ½″ to the left of the upper right corner. Connect these two points. Bisect this line with the dividers and draw a perpendicular bisector by the method of Fig. 7. On these two lines mark points ⅝″ apart and through these points, without moving the T-square, draw the lines of the two systems.

(9) **A Six-pointed Star.**—Fig. 58. For compasses and 30°–60° triangle. Draw a 4″ construction circle and inscribe the six-pointed star with the T-square and 30°–60° triangle. Accomplish this with four successive changes of position of the triangle.

(10) **A Trefoil.**—Fig. 59. For compasses, 30°–60° triangle and scale. Draw a 4″ circle. With 30°–60° triangle, draw 3 radii 120° apart. With mid-point of each radial line as center, draw a circle tangent to the 4″ circle. With same centers, draw smaller circles tangent to the other two 2″ circles. Connect centers to cut out middle of trefoil. Complete the figure, making all bands the same width.

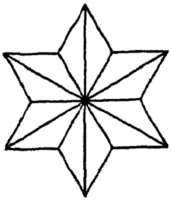


Fig. 58.

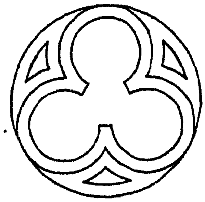


Fig. 59.

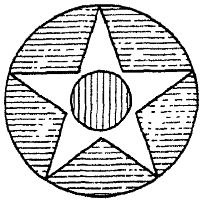


Fig. 60.

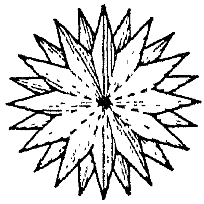


Fig. 61.

(11) **Aircraft Insigne.**—Fig. 60. This device is a white star with red center on a blue background. Draw 4″ circle and a 1¼″ circle. Divide large circle into five equal parts with the dividers and construct star by connecting alternate points as shown. Red is indicated by vertical lines and blue by horizontal lines. Space these by eye approximately 1⁄16″ apart. (Standard line symbols for colors are given in Fig. 1059.)

(12) **A 24-point Star.**—Fig. 61. For T-square and triangles in combination. In a 4″ circle draw 12 diameters 15° apart, using T-square and triangles singly and in combination. With the same combinations, finish the figure as shown.

(13) **A Quatrefoil Knot.**—Fig. 62. For accuracy with compasses. On horizontal and vertical center lines draw a 2″ square. With the middle points of its sides as centers draw semicircles 2″ and 1½″ in diameter. With the corners of the square as centers draw quadrants to complete the figure.

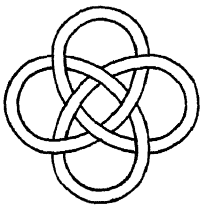


Fig. 62.

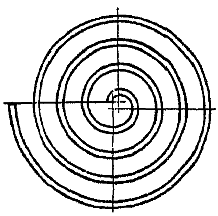


Fig. 63.

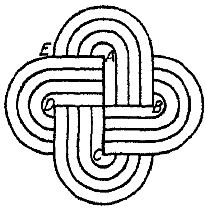


Fig. 64.

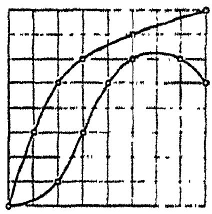


Fig. 65.

(14) **A Four-centered Spiral.**—Fig. 63. For accurate tangents. Draw a ⅛″ square and extend its sides as shown. With the upper right corner as center, draw quadrants with ⅛″ and ¼″ radii. Continue with quadrants from each corner in order until four turns have been drawn.

(15) **A Loop Ornament.**—Fig. 64. For bow compasses. Draw a 2″ square, about center of space. Divide *AE* into four ¼″ spaces, with scale. With bow pencil and centers *A*, *B*, *C*, *D* draw four semicircles with ¼″ radius, and so on. Complete figure by drawing the horizontal and vertical tangents as shown.

(16) **A Rectilinear Chart.**—Fig. 65. For French curve. Draw a 4″ field with ½″ coordinate divisions. Plot points at the intersections shown and through them sketch

a smooth curve very lightly in pencil. Finish by marking each point with a $\frac{1}{16}''$ circle and drawing a smooth bright line with the French curve.

(17) **Scale Practice.**—Fig. 66. *a.* Measure lines *A* to *G* to the following scales: *A*, full size; *B*, half size; *C*, 3″ = 1′-0″; *D*, 1″ = 1′-0″; *E*, $\frac{3}{4}''$ = 1′-0″; *F*, $\frac{1}{4}''$ = 1′-0″; *G*, $\frac{3}{16}''$ = 1′-0″.

b. Lay off distances on lines *H* to *N* as follows: *H*, $3\frac{3}{16}''$, full size; *I*, 7″, half size; *J*, 2′-6″, scale $1\frac{1}{2}''$ = 1′-0″; *K*, 7′-$5\frac{1}{2}''$, scale $\frac{1}{2}''$ = 1′-0″; *L*, 10′-11″, scale $\frac{3}{8}''$ = 1′-0″; *M*, 28′-4″, scale $\frac{1}{8}''$ = 1′-0″; *N*, 40′-10″, scale $\frac{3}{32}''$ = 1′-0″.

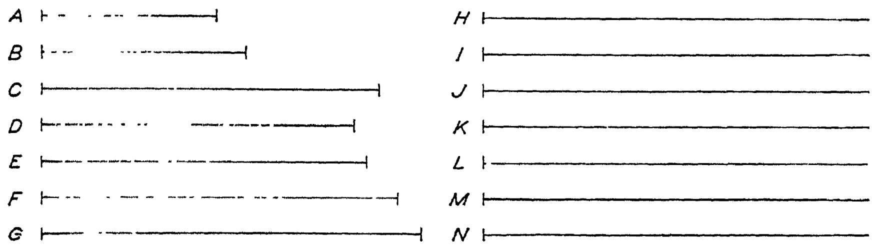


Fig. 66.

c. For Engineers' Scale.—Lay off distances on lines *H* to *N* as follows: *H*, 3.2″, full size; *I*, 27′-0″, scale 1″ = 10′-0″; *J*, 66′-0″, scale 1″ = 20′-0″; *K*, 105′-0″, scale 1″ = 30′-0″; *L*, 156′-0″, scale 1″ = 40′-0″; *M*, 183′-0″, scale 1″ = 50′-0″; *N*, 214′-0″, scale 1″ = 60′-0″.

(18) **A Motor-lamination Stamping.**—Fig. 67. Outside diameter, 5″; center to center of $\frac{1}{4}''$ holes, 4″; inside diameter, $2\frac{1}{2}''$; center to center of slot, $3\frac{11}{16}''$; width of slot, $\frac{9}{16}''$. Mark tangent points in pencil.

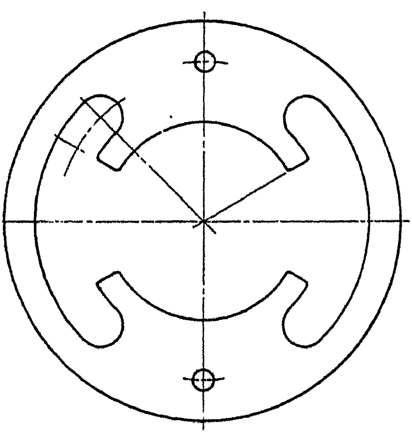


Fig. 67.—A stamping.

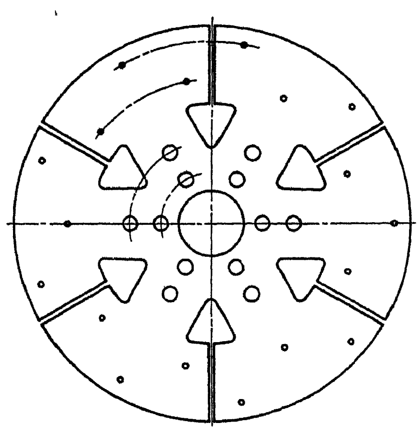


Fig. 68.—A clutch plate.

(19) **A Clutch Plate.**—Fig. 68. Outside diameter, $10\frac{3}{4}''$; bore, $1\frac{3}{4}''$; width of face, $2\frac{1}{8}''$. The arms (extended) are tangent to a 2″ circle at the center and are $1\frac{1}{2}''$ wide at intersection with inside diameter of face. Fillets have $\frac{1}{4}''$ radius. Slots are $\frac{1}{8}''$ wide. Diameter of outside rivet circle, $9\frac{3}{4}''$; inside rivet circle, $7\frac{3}{4}''$, for nine $\frac{1}{8}''$ holes equally spaced. On a $4\frac{3}{8}''$ and a $2\frac{3}{4}''$ circle, space six $\frac{3}{8}''$ holes each. Mark tangent points in pencil.

(20) **A Telephone Dial Plate.**—Fig. 69. Draw double size from dimensions given.
(21) **A Heraldic Rose.**—Fig. 70. Draw full size.
(22) **A Film-reel Stamping.**—Fig. 71. Draw full size.
(23) **A Film-reel Stamping.**—Fig. 72. Draw to scale of 6″ = 1′.

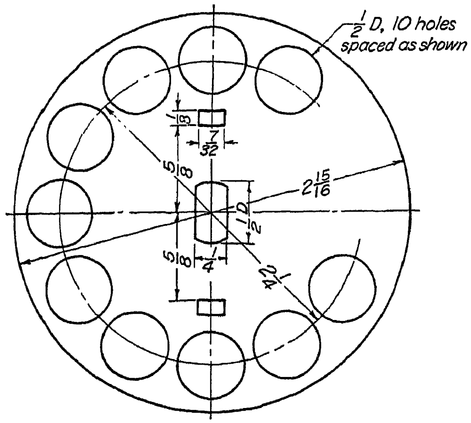


FIG. 69.—A telephone dial plate.

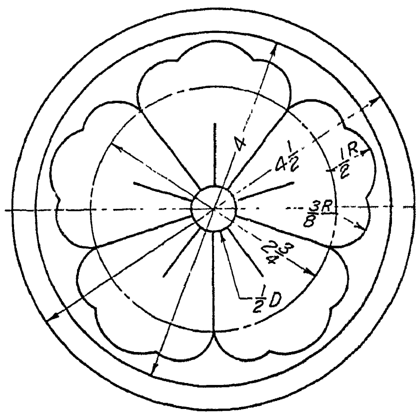


FIG. 70.—A heraldic rose.

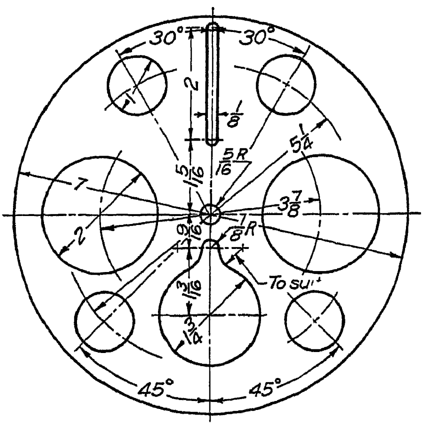


FIG. 71.—A film reel stamping.

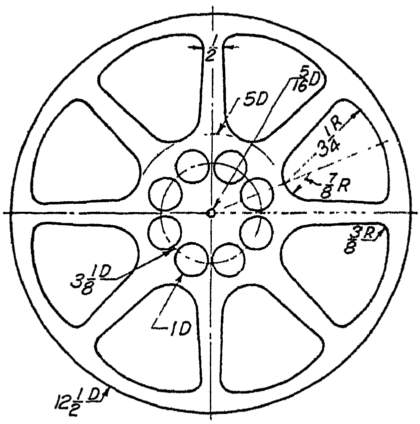


FIG. 72.—A film reel stamping.

(24) **Box Cover.**—Make one-view drawing for rectangular stamping 3″ × 4″, corners rounded with $\frac{1}{2}''$ radius. Four holes, one in each corner, $\frac{3}{16}''$ diameter, 3″ and 2″ center to center, for fastenings. Rectangular hole in center $\frac{3}{8}''$ × 1″ with 1″ side parallel to 4″ side. Two slots $\frac{1}{4}''$ wide, 2″ long with semicircular ends, located midway between center and 4″ edges with 2″ side parallel to 4″ side, and centered between 3″ edges.

(25) **Spacer.**—Make one-view drawing for circular stamping 4″ OD, 2″ ID. Six $\frac{1}{4}''$ diameter holes equally spaced on 3″ diameter circle, with two holes on vertical center line. Two semicircular notches 180° apart made with $\frac{3}{8}''$ radius centered at intersections of horizontal center line and 4″ OD circle.

(26) **Blank for Wheel.**—Make one-view drawing for stamping 5″ OD; center hole $\frac{1}{2}''$ diameter; eight spokes $\frac{3}{8}''$ wide connecting $1\frac{1}{2}''$ diameter center portion with $\frac{1}{2}''$ rim. Eight $\frac{1}{4}''$ diameter holes with centers at intersection of centerlines of spokes and $4\frac{1}{2}''$ circle, $\frac{1}{8}''$ fillets throughout, to break sharp corners.

A PAGE OF CAUTIONS

Never use the scale as a ruler.
Never draw with the lower edge of the T-square.
Never cut paper with a knife and the edge of the T-square as a guide.
Never use the T-square as a hammer.
Never put either end of a pencil into the mouth.
Never work with a dull pencil.
Never sharpen a pencil over the drawing board.
Never jab the dividers into the drawing board.
Never oil the joints of compasses.
Never use the dividers as reamers or pincers or picks.
Never lay a weight on the T-square to hold it in position.
Never use a blotter on inked lines.
Never screw the pen adjustment past the contact point of the nibs.
Never run backward over a line with either pencil or pen.
Never leave the ink bottle uncorked.
Never hold the pen over the drawing while filling.
Never dilute ink with water. If too thick throw it away.
Never put into the drawing-ink bottle a writing pen which has been used in ordinary writing ink.
Never try to use the same thumbtack holes in either paper or board when putting paper down a second time.
Never scrub a drawing all over with an eraser after finishing. It takes the life out of the inked lines.
Never begin work without wiping off table and instruments.
Never put instruments away without cleaning. This applies with particular force to pens.
Never put bow instruments away without opening to relieve the spring.
Never fold a drawing or tracing.

CHAPTER IV

LETTERING

To give all the information necessary for the complete construction of a machine or structure there must be added to the "graphical language" of lines describing its shape, the figured dimensions, notes on material and finish, and a descriptive title, all of which must be lettered, freehand, in a style that is perfectly legible, uniform and capable of rapid execution. So far as its appearance is concerned there is no part of a drawing so important as the lettering. A good drawing may be ruined, not only in appearance but in usefulness, by lettering done ignorantly or carelessly, as illegible figures are very apt to cause mistakes in the work.

28. The paragraph above refers to the use of lettering on engineering drawings. In a broad sense the subject of lettering is a distinct branch of design. There are two general classes of persons who are interested in its study: first, those who have to use letters and words to convey information on drawings; second, those who use lettering in applied design, as art students, artists and craftsmen. The first class is concerned mainly with legibility and speed, the second with beauty of form and composition. Architects come under both classes, as they have not only to letter their working drawings but to design inscriptions and tablets to be executed in stone or bronze.

The engineering student takes up lettering as his first work in drawing and continues its practice throughout his course, becoming more and more skillful and proficient.

In the art of lettering there are various forms of alphabets used, each appropriate for some particular purpose. The parent of all these styles is the "Old Roman" of the Classic Roman inscriptions. This beautiful letter is the basic standard for architects and artists, although they have occasional appropriate use for other forms, such as the gothic of the Middle Ages, one form of which is popularly known as **"Old English."** A variation

known as Modern Roman is used by civil engineers in finished map and topographical drawing. For working drawings the simplified forms called commercial gothic are used almost exclusively.

There are two general divisions of lettering: *drawn*, or *built-up* letters, and *written* or *single-stroke* letters. Roman letters are usually drawn in outline and filled in; commercial gothic, except in the larger sizes, are generally made in single stroke.

Lettering is *not* mechanical drawing. Large, carefully drawn letters are often made with instruments, but the persistent use by some draftsmen of mechanical caricatures known as "geometrical letters," "block letters," etc., made up of straight lines ruled in with T-square and triangle is to be condemned entirely.

29. General Proportions.—There is no one standard for the proportions of letters, but there are certain fundamental points in design and certain characteristics of individual letters that must be thoroughly learned by study and observation before composition into words and sentences may be attempted. Not only do the widths of letters in any alphabet vary, from *I* the narrowest, to *W*, the widest, but different alphabets vary as a whole. Styles narrow in their proportion of width to height are called **"COMPRESSED LETTERS"** and are used when space is limited. Styles wider than the normal are called "EXTENDED LETTERS."

The proportion of the thickness of stem to the height varies widely, ranging all the way from one-third to one-twentieth. Letters with heavy stems are called **boldface** or **blackface**, those with thin stems LIGHTFACE.

30. The Rule of Stability.—In the construction of letters the well-known optical illusion in which a horizontal line drawn across the middle of a rectangle appears to be below the middle must be provided for. In order to give the appearance of stability, such letters as *BEKSXZ* and the figures 3 and 8 must be drawn smaller at the top than at the bottom. To see the effect of this illusion turn a printed page upside down and notice the letters mentioned.

31. Single-stroke Lettering.—By far the greatest amount of lettering on drawings is done in a rapid single-stroke letter, either vertical or inclined, and every engineer must have absolute command of these styles. The ability to letter well can be acquired only by continued and careful practice, but it can be acquired by anyone with normal muscular control of his fingers who will practice faithfully and intelligently and take the trouble to observe carefully the shapes of the letters, the sequence of strokes in making them and the rules for their composition. It is not a matter of artistic talent or even of dexterity in handwriting. Many draftsmen who write very poorly letter well.

The terms "single-stroke" or "one-stroke" do not mean that the entire letter is made without lifting the pencil or pen, but that the width of the stroke of the pencil or pen is the width of the stem of the letter.

32. Guide Lines.—Light guide lines for both tops and bottoms of letters should always be drawn, using a sharp pencil. Figure 73 shows a method of laying off a number of equally spaced lines of letters. Draw the first base line and above it mark the desired height of the letters, then set the bow-spacers to the distance wanted between base lines and step off the

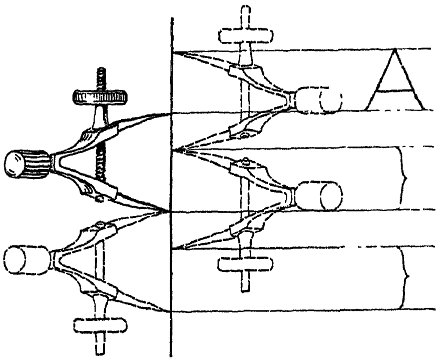


FIG. 73.—Spacing lines.

required number of base lines. With the same setting step down again from the upper point, thus obtaining points for the tops of each line of letters.

The Braddock-Rowe triangle, Fig. 74, and the Ames lettering instrument, Fig. 75. are convenient devices for spacing lines of letters. A sharp

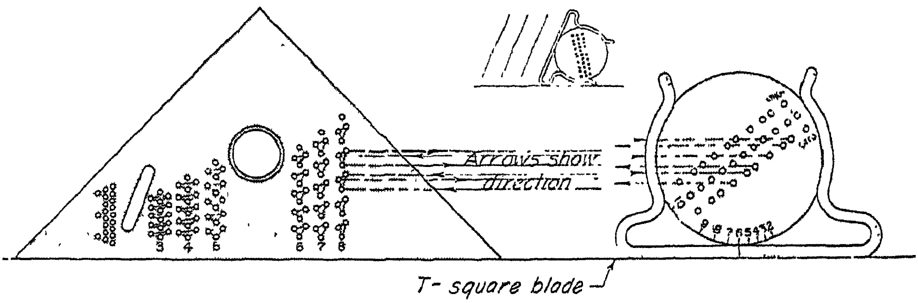


FIG. 74.—Braddock-Rowe triangle. FIG. 75.—Ames lettering instrument.

pencil is inserted in the proper row of countersunk holes, and the instrument, guided by a T-square blade, is drawn back and forth by the pencil. The holes are grouped for capitals and lower case, the numbers indicating the height of capitals in thirty-seconds of an inch; thus No. 6 spacing means that the capitals will be $\frac{6}{32}''$, or $\frac{3}{16}''$, high.

33. Lettering in Pencil.—In the previous chapter the necessity for fine pencil work in drawing was emphasized. This is equally true for lettering, since practically all lettering is done in pencil, either as finished work to be reproduced by one of the printing processes, or as part of a pencil drawing to be inked. In the first case the penciling will be clean, firm and opaque while

in the second case it may be lighter. The lettering pencil should be selected carefully by trial on the paper. In one case the same grade as that used for the drawing may be chosen, in another case a grade or two softer may be

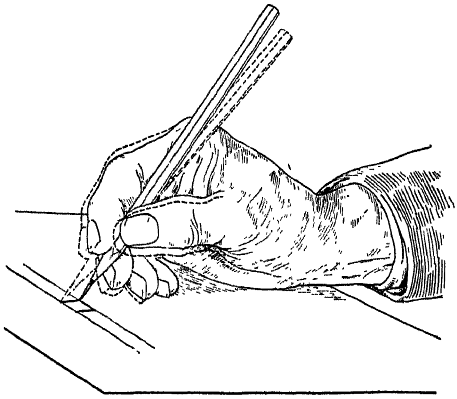


FIG. 76.—Vertical strokes.

preferred. Sharpen the pencil to a long conical point, then round the lead slightly on the end so that it is not so sharp as a point used for drawing.

The first requirement in lettering is the correct holding of the pencil or pen. Figure 76 shows the pencil held, comfortably, with the thumb, fore-

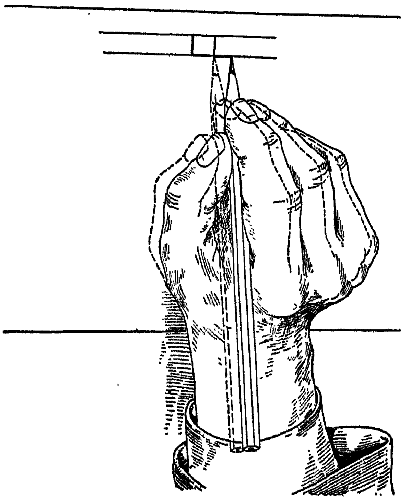


FIG. 77.—Horizontal strokes.

finger and second finger on alternate flat sides, and the third and fourth fingers on the paper. Vertical, slanting and curved strokes are drawn with a steady, even, finger movement, while horizontal strokes are made by pivoting the hand at the wrist, Fig. 77. Exert a firm uniform pressure but

not so heavy as to cut grooves in the paper. To keep the point symmetrical the habit of rotating the pencil after every few strokes should be formed.

LEONARDT 516 F: 506 F
HUNT 512: ESTERBROOK 968
Esterbrook 1000 Spencerian No. 1
Gillott 404: Gillott 303 For very fine lines Gillott 170 and 290 or Esterbrook 356 and 355

FIG. 78.—Pen strokes, full size.

34. Lettering Pens.—There are many steel writing pens either adaptable to or made especially for lettering. The sizes of strokes of a few popular ones are shown in full size in Fig. 78. Several special pens made in sets of graded sizes have been designed for single-stroke lettering, among which

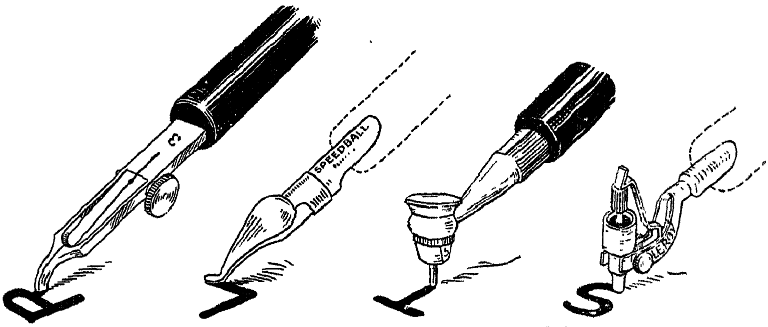


FIG. 79.—Barch-Payzant, Speedball, Edco and Leroy pens.

are those illustrated in Fig. 79. These are particularly useful for large work. The ink-holding reservoir of the Henry tank pen, Fig. 80, assists materially in maintaining uniform weight of line. A similar device may be made by bending a brass strip from a paper fastener, a piece of annealed watch

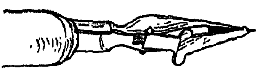


FIG. 80.—Henry tank pen.

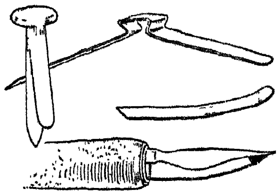


FIG. 81.—Ink holder.

spring or, perhaps best, a strip cut from a piece of shim brass into the shape shown in Fig. 81 and inserting it in the penholder so that the curved end just touches the nibs of the pen. The rate of feed is increased by moving the end closer to the point of the pen.

Always wet a new pen and wipe it thoroughly before using, to remove the oil film. Some draftsmen prepare a new pen by holding it in a match flame for 2 or 3 seconds. A lettering pen well broken in by use is worth much more than a new one. It should be kept with care and never lent. A pen that has been dipped into writing ink should never be put into drawing ink. When in use a pen should be wiped clean frequently with a cloth penwiper. The use of a ruling pen for freehand lettering is not recommended.

35. Using the Pen.—A penholder with cork grip (the small size) should be chosen and the pen set in it firmly. Many prefer to ink the pen with the quill filler, touching the quill to the underside of the pen point, rather than to dip it into the ink bottle. If the pen is dipped, the surplus ink should be shaken back into the bottle or the pen touched against the neck of the bottle as it is withdrawn. Lettering with too much ink on the pen is responsible for results of the kind shown in Fig. 82.

FIG. 82.—Too much ink.

With the penholder in the position shown in Fig. 83 it should rest, rather than be held, in the fingers, so loosely that it could be pulled out easily with the other hand. Never tighten the grip of the fingers. The strokes of the letters should be made with a steady even motion and a slight uniform pressure on the paper, not enough to spread the nibs of the pen.

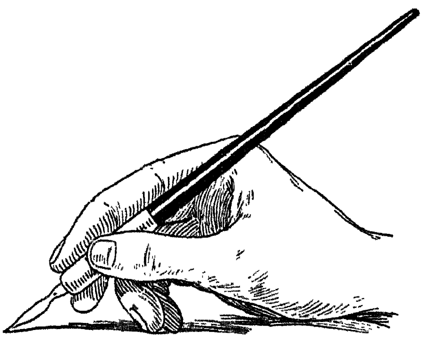


FIG. 83.—Holding the pen.

36. Single-stroke Vertical Capitals. The vertical single-stroke commercial gothic letter is a standard for titles, reference letters, etc. As to the proportion of width to height the general rule is that the smaller the letters the more extended should they be in width. A low extended letter is more legible than a high compressed one and at the same time makes a better appearance. This letter is seldom used in compressed form.

The basic requirement is to learn the form and peculiarity of each of the letters. Too many persons think that lettering is simply "printing" of the childish kind learned in the primary grades. There is an individuality in lettering often nearly as marked as in handwriting but it must be based on a careful regard for the fundamental letter forms.

37. Order of Strokes.—In the following figures an alphabet of slightly extended vertical capitals has been arranged in family groups. The shape of each letter, with the order and direction of the strokes forming it, must be studied carefully and the letter repeatedly practiced, until its form and construction are perfectly familiar. The first studies should be made in pencil to large size. perhaps ⅜″ high, afterward to smaller size and finally directly in ink.

To aid in seeing the proportions of widths to heights and in learning the subtleties in the shapes of the letters, they are shown against a square background with its sides divided into sixths. It will be noted that several of the letters in this alphabet, as *A*, *T*, etc., fill the square, that is, are as wide as they are high, while some others, as *H*, *D*, etc., are approximately five spaces wide, or five-sixths of their height. *These proportions must be learned visually* so well that letters of various heights can be drawn in correct proportion without hesitation. With paper and pencil in hand study the groups in order.

The IHT Group.—Fig. 84. The letter *I* is the foundation stroke. It may be found difficult to keep the stems vertical. If so, direction lines may be drawn lightly an inch or so apart, to aid the eye. The *H* is nearly square (five-sixths), and, in accord with the rule of stability, the crossbar is just above the center. The top of the *T* is drawn first to the full width of the square and the stem started accurately at its middle point.

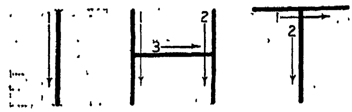


FIG. 84.

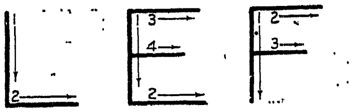


FIG. 85.

The LEF Group.—Fig. 85. The *L* is drawn in two strokes. Note that the first two strokes of the *E* are the same as the *L*, that the third or upper stroke is slightly shorter than the lower and that the last stroke is two-thirds as long and just above the middle. *F* has the same proportions as *E*.

The NZXY Group.—Fig. 86. The parallel sides of *N* are generally drawn first, but some prefer to make the strokes in consecutive order. *Z* and *X* are both started inside the width of the square on top and run to full width on the bottom. This throws the crossing point of the *X* slightly above the center. The junction of the *Y* strokes is just below the center.

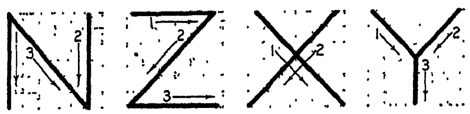


FIG. 86.

The VAK Group.—Fig. 87. *V* is slightly narrower than *A*, which here is full width of the square. Its bridge is one-third up from the bottom. The second stroke of *K* strikes the stem one-third up from the bottom; the third stroke branches from it in a direction starting from the top of the stem.

FIG. 87.

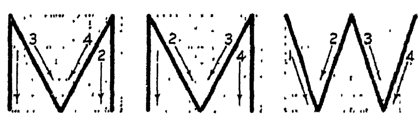


FIG. 88.

The MW Group.—Fig. 88. These are the widest letters. *M* may be made either in consecutive strokes or by drawing the two vertical strokes

first, as with the *N*. *W* is formed of two narrow *V*'s, each two-thirds of the square in width. Note that with all the pointed letters the width at the point is the width of the stroke, that is, the center lines of the strokes meet at the guide lines.

The OQCG Group.—Fig. 89. In this extended alphabet the letters of the *O* family are made as full circles. The *O* is made in two strokes, the

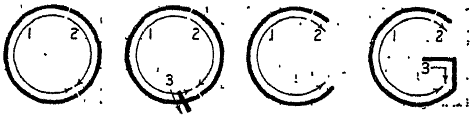


Fig. 89.

left side a longer arc than the right, as the right side is harder to draw. Make the kern of the *Q* straight or nearly straight. *C* and *G* of large size can be drawn more accurately with an extra stroke at the top, while in smaller ones the curve is drawn in one stroke. See Fig. 97. Note that the bar on the *G* is halfway up and does not extend past the vertical line.

The DUJ Group.—Fig. 90. The top and bottom strokes of *D* must be horizontal. Failure to observe this is a common fault with beginners. *U* in larger letters is formed of two parallel strokes to which the bottom stroke is added. For smaller letters it may be made in two strokes curved at the bottom to meet. *J* has the same construction as *U*.

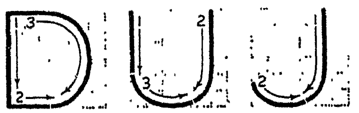


Fig. 90.

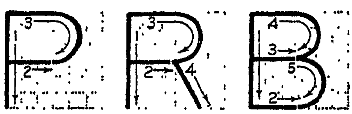


Fig. 91.

The PRB Group.—Fig. 91. With *P*, *R* and *B*, the number of strokes used depends upon the size of the letter. For large letters the horizontal lines are started and the curves added, but for smaller letters only one stroke for each lobe is needed. The middle lines of *P* and *R* are on the center line, that of *B* observes the rule of stability.

The S83 Group.—Fig. 92. The *S*, *8* and *3* are closely related in form, and the rule of stability must be observed carefully. For a large *S*, three

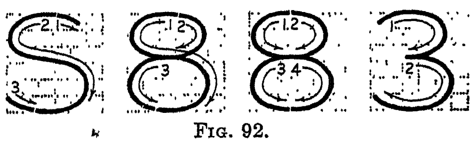


Fig. 92.

strokes may be used, for a smaller one, two strokes, and, for a very small size, one stroke only is best. The *8* may be made on the *S* construction in three strokes, or in "head and body" in four strokes. A perfect *3* should be capable of being finished into an *8*. The *3* with flat top, sometimes seen, should not be used, on account of the danger of mistaking it for a *5*.

The 069 Group.—Fig. 93. The cipher is slightly narrower than the letter *O*. The backbones of the *6* and *9* have the same curve as the cipher, and the lobes are two-thirds the height of the figure.

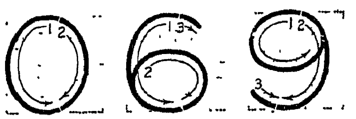


Fig. 93.

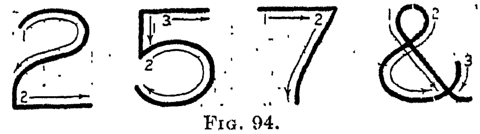


Fig. 94.

The 257& Group.—Fig. 94. The secret in making the *2* lies in getting the reverse curve to cross the center of the space. The bottom of *2* and the tops of *5* and *7* should be horizontal straight lines. The second stroke of *7* terminates directly below the middle of the top stroke. Its stiffness is relieved by curving it slightly at the lower end. The ampersand (&) is made in three strokes for large letters and two for smaller ones and must be carefully balanced.

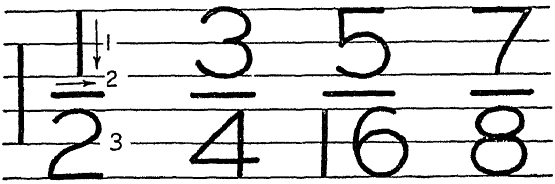


Fig. 95.

The Fraction Group.—Fig. 95. Fractions are always made with horizontal bar. The figures are two-thirds the height of the whole numbers, with a clear space above and below the bar, making the total height of the fraction five-thirds the cap height. Much practice should be given to numerals and fractions. A useful practice sheet of figures alone may be made by designing a table of decimal equivalents. See Appendix for table.

38. Vertical Lower Case.—The single-stroke vertical lower-case letter is not commonly used on machine drawings but is used extensively in map drawing. It is the standard letter for hypsography in government topo-

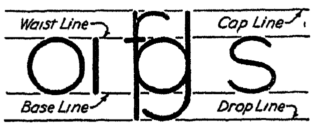


Fig. 96.

graphical drawing. The bodies are made two-thirds the height of the capitals, with the ascenders extending to the cap line and the descenders dropping the same distance below. The basis of the letter as used with the extended capitals just analyzed is the combination of a circle and a straight line as shown in enlarged form in Fig. 96. The alphabet with some alternate

shapes is shown in Fig. 97, which also gives the capitals in alphabetical order.

39. Single-stroke Inclined Caps.—The inclined or slant letter is used in preference to the upright by many, including the majority of structural-steel draftsmen. The order and direction of strokes are the same as in the vertical form.

FIG. 97.—Single-stroke vertical caps and lower-case.

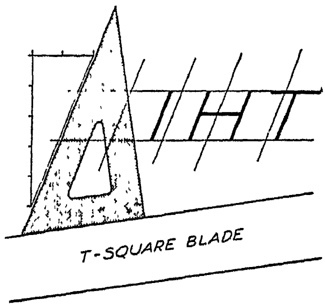


FIG. 98.—Slope guide lines.

After ruling the guide lines, slanting "direction lines" should be drawn across the sheet to aid the eye in keeping the slope uniform. These slope lines may be drawn with a special lettering triangle of about 67½°, or the slope of 2 to 5 may be fixed on the paper by marking two units on a horizontal line and five on a vertical line, and using T-square and triangle as shown in Fig. 98. The form taken by the rounded letters when inclined is

illustrated in Fig. 99, which shows that curves are sharp in all upper right-hand and lower left-hand corners and flattened in the other two corners. The snap and swing of professional work is due to three things: first, to keeping to a uniform slope, second, to having the letters full and well shaped and, third, to keeping them close together. The beginner's invariable mistake is to cramp the individual letters and space them too far apart.

FIG. 99.

FIG. 100.

Particular care must be observed with the letters having sloping sides as *A*, *V* and *W*. The sloping sides of these letters must be drawn so that they appear to balance about a slope guide line through their intersection, as in Fig. 100. The alphabet is given in Fig. 101. Study the shape of each letter carefully.

FIG. 101.—Single-stroke inclined caps and lower-case.

40. Single-stroke Inclined Lower Case.—The inclined lower-case letters, Fig. 101, have the bodies two-thirds the height of the capitals, with the ascenders extending to the cap line and the descenders dropping the same distance below the base line. This letter is generally known among older engineers, particularly among civil engineers, as the Reinhardt letter, in honor of Charles W. Reinhardt, who first systematized its construction.

It is very legible and effective and after its swing has been mastered can be made very rapidly. The lower-case letter is suitable for notes and statements on drawings for the two reasons indicated: first, it is read much more easily than all caps, since we read words by the word shapes, and, second, it can be done much faster.

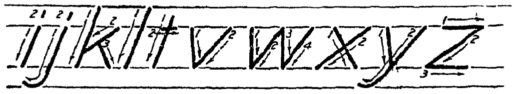


FIG. 102.—The straight-line letters.

All the letters of the Reinhardt alphabet are based on two elements: the straight line and the ellipse, and have no unnecessary hooks or appendages. They may be divided into four groups as shown in Figs. 102 to 105. The dots of *i* and *j* and the top of the *t* are on the "t-line," halfway between the waistline and the cap line. The loop letters are made with an ellipse whose long axis is inclined about 45°, in combination with a straight line. In lettering rapidly, this ellipse tends to assume a pumpkin-seed form which should be guarded against.

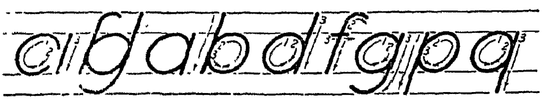


FIG. 103.—The loop letters.

FIG. 104.—The ellipse letters.

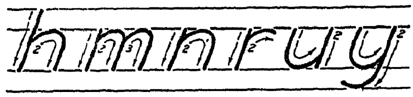


FIG. 105.—The hook letters.

The *c*, *e*, and *o* are based on an ellipse of the shape of the capitals, not inclined quite so much as the loop-letter ellipse. In rapid, small work the *o* is often made in one stroke, as are also *e*, *v* and *w*. The *s* is similar to the capital but except in letters more than ⅛ inch high is made in one stroke. In the hook-letter group, note particularly the shape of the hook.

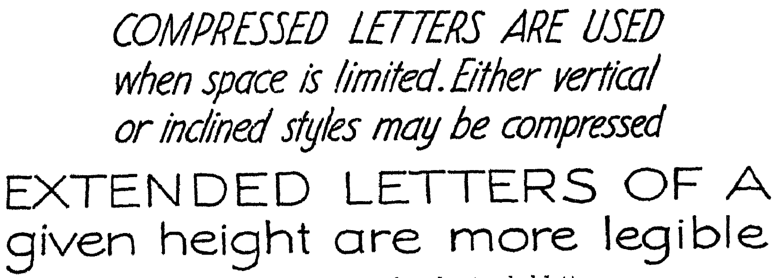


FIG. 106.—Compressed and extended letters.

The single-stroke letter may, if necessary, be very much compressed and still be clear and legible, Fig. 106. It is also used sometimes in extended form.

41. For Left-handers Only.—The order and direction of strokes in the preceding alphabets have been designed for right-handed persons. The principal reason that left-handers sometimes find lettering difficult is that,

whereas the right-hander progresses away from the body, the left hander progresses toward the body, consequently his pencil and hand partially hide the work he has done, making it harder to join strokes and to preserve uniformity. Also, in the case of inclined lettering, the slope direction, instead of running toward his eye, runs off into space to the left of his body, making this style so much harder for him that the left-hander is strongly advised to *use vertical letters exclusively.*

For the natural left-hander whose writing position is the same as a right-hander except reversed left for right, a change in the sequence of strokes of some of the letters will obviate part of the difficulty caused by interference with the line of sight. Figure 107 gives an analyzed alphabet

FIG. 107.—Strokes for left-handers.

with an alternate for some letters. In *E* the top bar is made before the bottom bar and *M* is drawn from left to right, to avoid having strokes hidden by the pencil or pen. Horizontal curves are easier to make from right to left, hence the starting points for *O*, *Q*, *C*, *G* and *U* differ from the standard right-hand stroking. *S* is the perfect letter for the left-hander and is best made in a single smooth stroke. *6* and *9* are difficult and should have extra practice. In the lower-case letters *a*, *d*, *g* and *q* it is better to draw the straight line before the curve even though it makes spacing a little harder.

The hook-wrist left-handed writer, who pushes his strokes from top to bottom finds vertical lettering more difficult than does the natural left-hander. In Fig 107 where alternate strokes are given for some of the letters, the hook-wrist writer will probably find the stroking of the second one easier for him than that of the first. Some prefer to reverse *all* the

strokes, drawing vertical strokes from bottom to top and horizontal strokes from right to left.

By way of encouragement it may be said that many left-handed draftsmen letter beautifully.

42. Composition.—Composition in lettering has to do with the selection, arrangement and spacing of appropriate styles and sizes of letters. On engineering drawings the selection of the style is practically limited to vertical or inclined single-stroke, so that composition here means arrangement into pleasing and legible form. After the shapes and strokes of the

FIG. 108.—Background areas.

individual letters have been learned the entire practice should be on composition into words and sentences, since proper spacing of letters and words does more for the appearance of a block of lettering than the forms of the letters themselves. Letters in words are not spaced at a uniform distance from each other but so that the areas of white spaces (the irregular backgrounds between the letters), are approximately equal, thus making the spacing *appear* approximately uniform. Figure 108 illustrates these background shapes. Each letter is spaced with reference to its shape and the shape of the letter preceding it. Thus adjacent letters with straight sides would be spaced farther apart than those with curved sides. Sometimes

FIG. 109.—Word composition.

combinations such as *LT* or *AV* may even overlap. Definite rules for spacing are not successful; it is a matter of the draftsman's judgment and sense of design. Figure 109 illustrates word composition. The sizes of letters to use in any particular case may be determined better by sketching them lightly than by judging from the guide lines alone. A finished line of letters always looks larger than the guide lines would indicate. Before inking a line of penciled letters, rub the pencil marks so the excess graphite will not "muddy" the ink. Avoid the use of a coarse pen for small sizes, and one that makes thin wiry lines for large sizes. When caps and small caps are used, the height of the small caps should be about four-fifths that of the caps.

In spacing words a good method is to leave the space that would be taken by an assumed letter *I* connecting the two words into one, as Fig. 110. The space would never be more than the height of the letters.

The clear distance between lines may vary from one-half to one and one-half times the height of the letter but for appearance's sake should not be exactly the same as the letter height. The instruments of Figs. 74 and 75 provide spacing two-thirds the letter height. Paragraphs should always be indented.

WORDSISPACEDIBYISKETCHINGIANIIIBETWEEN

WORDS SPACED BY SKETCHING AN I BETWEEN

Fig. 110.—Word spacing.

43. Titles.—The most important problem in lettering composition that the engineering draftsman will meet is the design of titles. Every drawing has a descriptive title giving the necessary information concerning it, which is either all hand-lettered or filled in on a printed form. This information, of course, is not the same for all kinds of drawings (see working-drawing titles, page 259; architectural titles, page 480; structural titles, page 491; map titles, page 514).

The usual form of lettered title is the *symmetrical title*, which is balanced or "justified" on a vertical center line and designed with an elliptical or oval

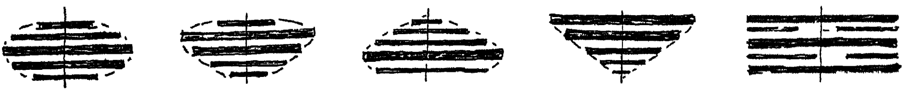


Fig. 111.—Shapes in symmetrical composition.

outline. Sometimes the wording necessitates a pyramid or inverted pyramid ("bag") form. Figure 111 illustrates several shapes into which titles can be composed. The lower right-hand corner of the sheet is, from long custom and on account of convenience in filing, the usual location for the title, and in laying out a drawing this corner is reserved for it. The space allowed is a matter of judgment and depends on the size and purpose of the drawing. On an 11″ × 17″ working drawing the title may be about three inches long.

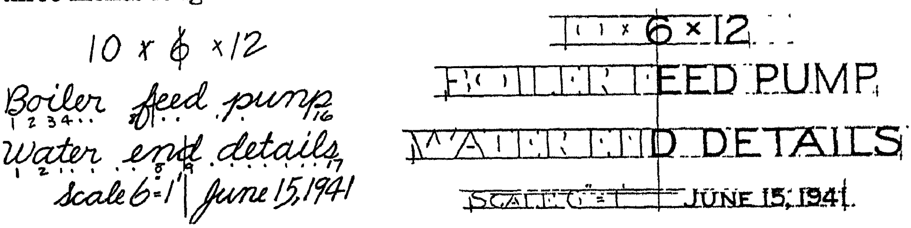


Fig. 112.—Title composition.

44. To Draw a Title.—When the wording has been determined, write out the arrangement on a separete piece of paper as in Fig. 112 (or, better,

typewrite it). Count the letters, including the word spaces and make a mark across the middle letter or space of each line. The lines must be displayed for prominence according to their relative importance as judged from the point of view of the persons who will use the drawing. Titles are usually made in all caps. Draw the base line for the most important line of the title and mark on it the approximate length desired. To get the letter height divide this length by the number of letters in the line, and draw the cap line. Start at the center line and sketch very lightly the last half of the line, drawing only enough of the letters to show the space each will occupy. Lay off the length of this right half on the other side and sketch that side, working either forward or backward. When this line is satisfactory in size and spacing, draw the remainder in the same way. Study the effect, shift letters or lines if necessary, and complete in pencil. Use punctuation marks only for abbreviations.

45. The Scratch-paper Methods.—Sketch each line of the title separately on a piece of scratch paper, using guide lines of determined height. Find the middle point of each of these lines, fold the paper along the base line of the letters, fit the middle point to the center line on the drawing, and draw the final letters directly below the sketches. *Or* draw the letters along the edge of the scratch paper, using either the upper or the lower edge as one of the guide lines. *Or* letter the title on scratch paper, cut apart and adjust until satisfactory and then trace it.

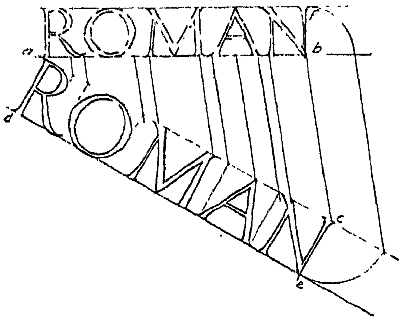


FIG. 113.—Proportional method.

46. The Proportional Method.—On account of the varying widths of Roman letters it is sometimes difficult to space a word or line to a given length by counting letters. Figure 113 illustrates the method of spacing by the principle of similar triangles. Suppose it is required to put the word "ROMAN" on the line and to the length of *ab*. A line *ac* is drawn from *a* at any angle (say 30°) and a second, *de*, parallel to it, then the word is sketched in this space, starting at *a* and spacing each letter with reference to the one before it, allowing the word to end where it will. The end of the last letter, at *c*, is connected with *b*, and lines parallel to *cb* are drawn from each letter, thus dividing *ab* proportionately. The height *bf* is obtained from

ce by the construction shown, after which the word can be sketched in its final position.

47. Outlined Commercial Gothic.—Thus far the so-called "gothic" letter has been considered only as a single-stroke letter. For sizes larger than, say, 5/16 inch, or for bold-faced letters, it is drawn in outline and filled in solid. For given size this letter is readable at a greater distance than any other style; hence it would be used in any place where legibility is the principal requirement. The stems may be from one-tenth to one-fifth of the height, and much care must be exercised in keeping them to uniform width at every point on the letter. In inking a penciled outline keep the *outside* of the ink line on the pencil line, Fig. 114; otherwise the letter will be heavier than expected.

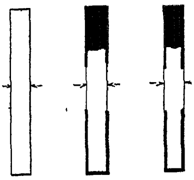


FIG. 114.

Making two strokes in place of one, the general order and direction of penciling large commercial gothic letters is similar to the single-stroke

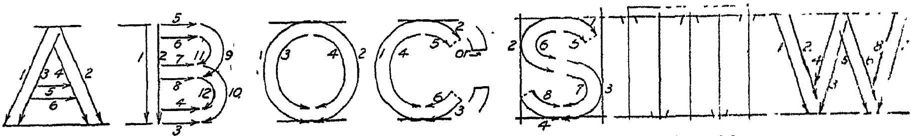


FIG. 115.—Typical construction for large commercial gothic.

analysis, as shown in the typical examples of Fig. 115. Free ends, such as on *C*, *G* and *S*, are cut off perpendicular to the stem. The stiffness of plain letters is sometimes relieved by finishing the ends with a slight spur as in

FIG. 116.—Compressed commercial gothic.

Fig. 116. The complete alphabet in outline, with stems one-sixth of the height, is given in Fig. 117. The same scale of widths may be used for drawing lighter face letters. Figure 116 illustrates a commercial gothic alphabet compressed to two-thirds the normal width. In this figure the

FIG. 117.—Large commercial gothic construction.

Fig. 118.—Old Roman capitals.

stems are drawn one-seventh of the height, but the scale is given in sixths as in Fig. 117.

48. The Roman Letter.—The Roman letter has been mentioned as the parent of all the styles, however diversified, which are in use today. Although there are many variations of it there may be said to be three general forms: (1) the early or classic, (2) the Renaissance, (3) the Modern. The first two are very similar in effect and the general term "Old Roman" is used for both.

The Roman letter is composed of two weights of lines, corresponding to the downstroke and the upstroke of the broad reed pen with which it was

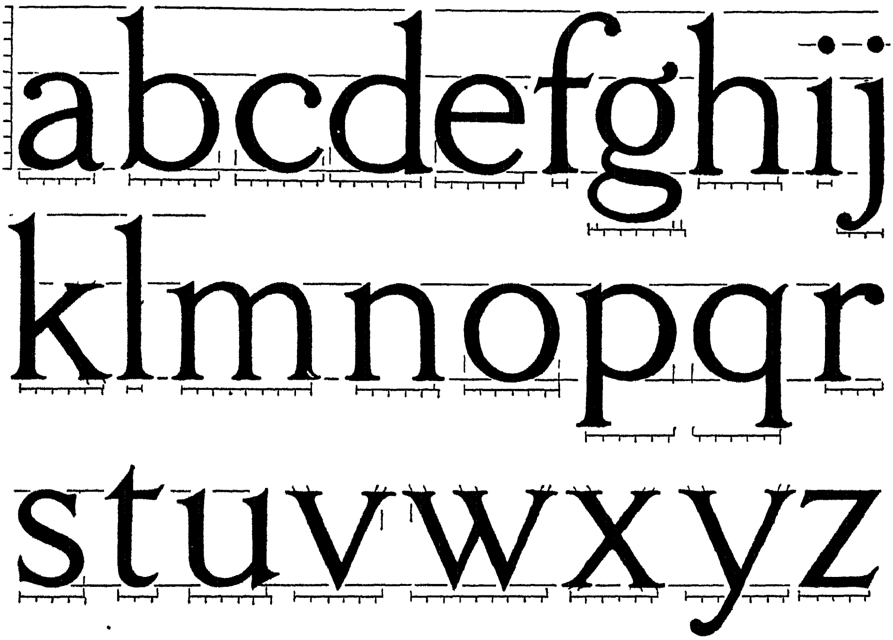


FIG. 119.—Old Roman lower case.

originally written. It is an inexcusable fault to shade a Roman letter on the wrong stroke.

Rule for Shading.—All horizontal strokes are light. All vertical strokes are heavy except in *M*, *N* and *U*. To determine the heavy stroke in letters containing slanting sides trace the shape of the letter from left to right in one stroke and note which lines were made downward. Figure 118 is an Old Roman alphabet with the width of the body stroke one-tenth of the height of the letter and the light lines slightly over one-half this width. For inscriptions and titles it is generally used in all capitals, but sometimes the lower case, Fig. 119, is needed. This figure is drawn with the waistline six-tenths high and the width of the stems one-twelfth of the cap height.

The Old Roman is the architect's one general-purpose letter. A single-stroke adaptation of it, Fig. 120, is generally used on architectural drawings.

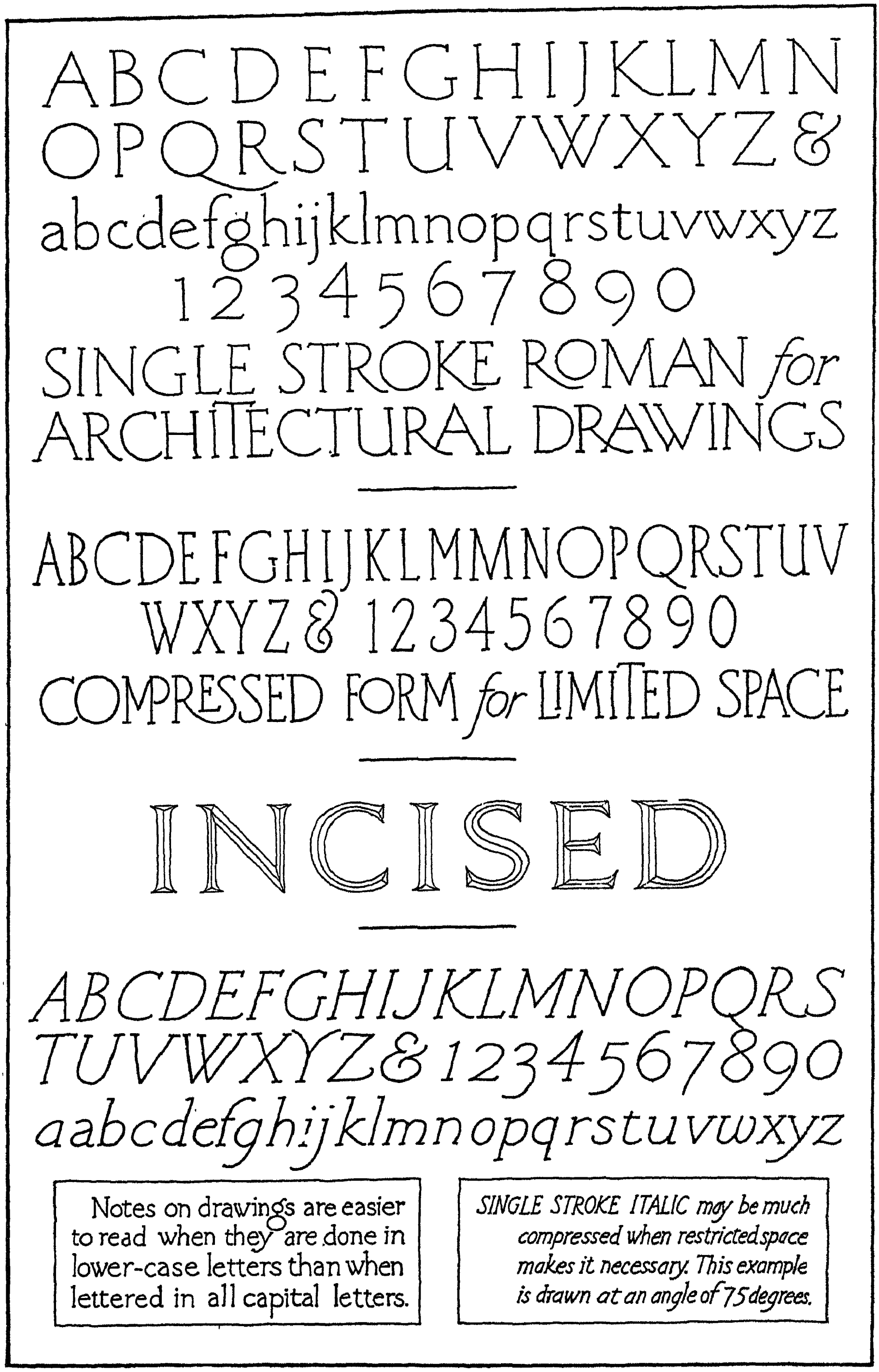


Fig. 120.—Single-stroke Roman and Italic.

49. Modern Roman.—Civil engineers in particular must be familiar with the Modern Roman, as it is the standard letter for finished map titles and the names of civil divisions, as countries and cities. It is a difficult letter to draw and can be mastered only by careful attention to details. The heavy or "body" strokes are from one-sixth to one-eighth the height of the letter.

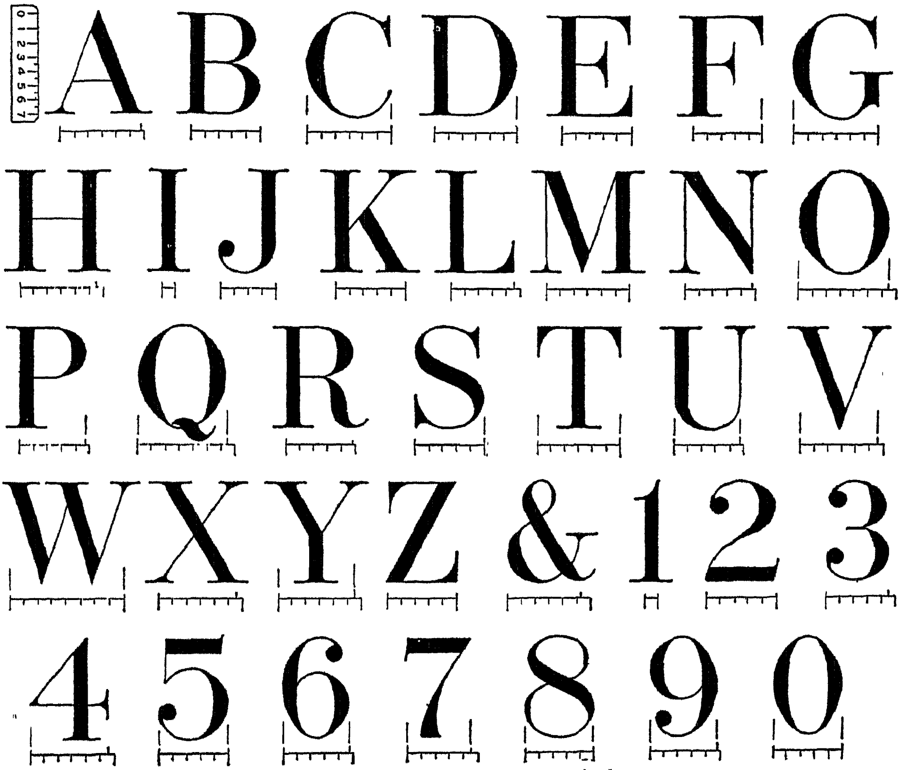


FIG. 121.—Modern Roman capitals.

FIG. 122.—Modern Roman lower case.

Those in Fig. 121 are one-seventh. A paper scale made by dividing the height into seven parts will aid in penciling. Modern lower case, Fig. 122, is used on maps for names of towns and villages. Notice the difference in the serifs of Figs. 122 and 119.

The order and direction of strokes used in drawing Roman letters are illustrated in the typical letters of Fig. 123. The serifs on the ends of the strokes extend one space on each side and are joined to the stroke by small

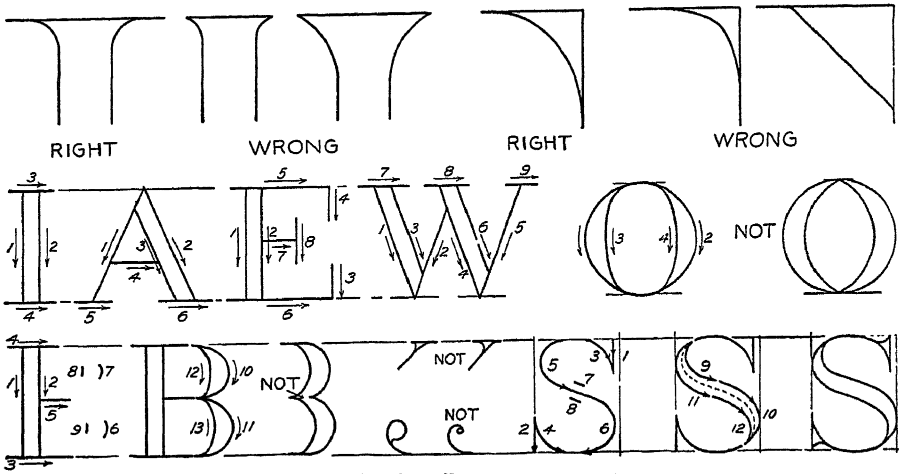


Fig. 123.—Modern Roman construction.

MAP SHOWING

IRON ORE DEPOSITS

IN THE

WESTERN STATES

SCALE-MILES 0 50 100 200 300 400

Fig. 124.—A Roman letter title.

fillets. Roman letters are spoiled oftener by poor serifs and fillets than in any other way. For letters smaller than ¼ inch it is best to omit the body-

EXTENDED ROMAN

BCGHJKLPQSUVW

COMPRESSED ROMAN-BHKTWG

Fig. 125.—Modern Roman, extended and compressed.

stroke fillets altogether. It will be noticed that the curved letters are flattened slightly on their diagonals. A title in Roman letters is illustrated in Fig. 124.

The Roman letter may be extended or compressed, as shown in Fig. 125. For these a scale for widths may be made longer or shorter than the normal

scale. For example, the compressed letters of Fig. 125 are made with a scale three-fourths of the height divided into sevenths.

50. Inclined Roman.—Inclined letters are used for water features on maps. An alphabet of inclined Roman made to the same proportions as the vertical of Fig. 121 is shown in Fig. 126. The slope may be from 65° to 75°.

FIG. 126.—Inclined Roman and stump letters.

Those shown are inclined 2 to 5. The lower-case letters in this figure are known as stump letters. For small sizes their lines are made with one stroke of a fine flexible pen, while larger sizes are drawn and filled in.

EXERCISES

The following exercises are designed for a 5″ × 7″ sheet or space. Lettering practice should be done in short intensive periods.

Series I. Single-stroke Vertical Caps

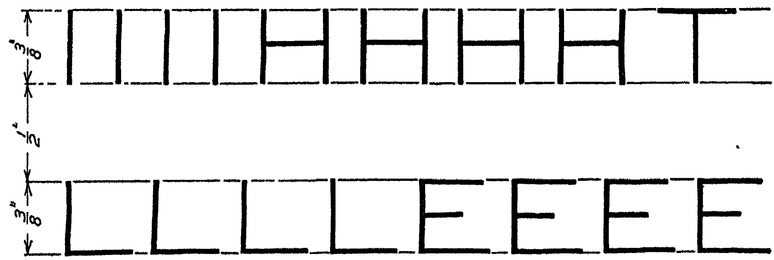


FIG. 127.

1. Large letters in pencil, for careful study of the shapes of the individual letters. Starting $\frac{9}{16}''$ from top border draw guide lines for five lines of $\frac{3}{8}''$ letters. Draw each

of the straight-line letters *IHTLEFNZYVAMWX* four times in pencil only, studying carefully Figs. 84 to 88. Figure 127 is a full-sized reproduction of a corner of this exercise.

2. Same as Ex. 1 for the curved line letters *OQCGDUJBPRS*. Study Figs. 89 to 92.

3. Same as Ex. 1 for figures 3, 8, 6, 9, 2, 5, $\frac{1}{2}$, $\frac{3}{4}$, $\frac{5}{8}$, $\frac{7}{16}$, $\frac{9}{32}$. Study Figs. 93 to 95.

4. Composition. Same layout as for Ex. 1. Read paragraph on composition, then letter the following five lines in pencil (1) WORD COMPOSITION, (2) TOPOGRAPHIC SURVEY, (3) TOOLS AND EQUIPMENT, (4) BRONZE BUSHING, (5) JACK-RAFTER DETAIL.

5. Quarter-inch vertical letters in pencil and ink. Starting $\frac{1}{4}''$ from top, draw guide lines for nine lines of $\frac{1}{4}''$ letters. In the group order given, draw each letter first four times in pencil, then four times directly in ink, as in Fig. 128.

6. Composition. Make a three-line design of the quotation from Benjamin Lamme on the Lamme Medals: "THE ENGINEER VIEWS HOPEFULLY THE HITHERTO UNATTAINABLE."

7. Eighth-inch vertical letters. Starting $\frac{1}{4}''$ from top, draw guide lines for 18 lines of $\frac{1}{8}''$ letters. Make each letter and numeral eight times directly in ink. Fill the remaining lines with a portion of paragraph 42 on composition.

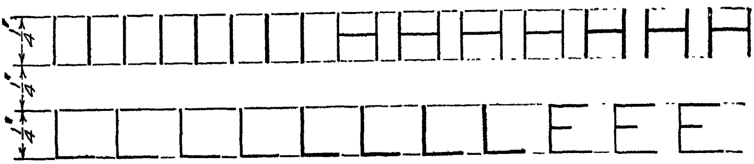


Fig. 128.

8. Composition. Letter the following definition: "Engineering is the art and science of directing and controlling the forces and utilizing the materials of nature for the benefit of man. All engineering involves the organization of human effort to attain these ends. It also involves an appraisal of the social and economic benefits of these activities."

Series II. Single-stroke Inclined Capitals

9 to 16. Same spacing and specifications as for Series I, Exs. 1 to 8, but for inclined letters. Study paragraph 39 and Figs. 98 to 101.

Series III. Single-stroke Inclined Lower Case

17. Large letters in pencil for use with $\frac{3}{8}''$ caps. The bodies are $\frac{1}{4}''$, the ascenders $\frac{1}{8}''$ above and the descenders $\frac{1}{8}''$ below. Starting $\frac{3}{8}''$ from top, draw guide lines for seven lines of letters. This can be done quickly by spacing $\frac{1}{8}''$ uniformly down the sheet and bracketing cap and base lines. Make each letter of the alphabet four times in pencil only. Study Figs. 101 to 105.

18. Lower case for $\frac{3}{16}''$ caps. Starting $\frac{1}{2}''$ from top, draw cap, waist- and base lines for 13 lines of letters (Braddock or Ames No. 6 spacing). Make each letter six times in pencil, then six times in ink.

19. Composition. Same spacing as Ex. 18. Letter opening paragraph of this chapter.

20. Letter the first ten lines of paragraph 31.

Series IV. Titles

21. Design a title for the assembly drawing of a rear axle, drawn to the scale of $6'' = 1$ ft., as made by the Chevrolet Motor Co., Detroit. The number of the drawing is C 8 2 7 4 6. Space allowed, $3'' \times 5''$.

22. Design a title for the front elevation of a powerhouse, drawn to quarter-inch scale by Burton Grant, Architect, for the Citizens Power and Light Company of Punxsutawney, Pennsylvania.

CHAPTER V

APPLIED GEOMETRY

51. With the aid of a straightedge and compasses all pure-geometry problems may be solved. The principles of geometry are constantly used in mechanical drawing, but as the geometrical solution of problems and construction of figures differ in many cases from the draftsman's method, equipped as he is with instruments for gaining time and accuracy, such problems are not included here. There are, for example, several geometrical methods of erecting a perpendicular to a given line; in his ordinary practice the draftsman equipped with T-square and triangles uses none of them. However, the application of these geometrical methods is necessary occasionally in work where the usual drafting instruments could not be used, as in laying out full-size sheet-metal patterns on the floor, or in aircraft lofting work. It is assumed that students using this book are familiar with the elements of plane geometry and will be able to apply their knowledge. If the solution of a particular problem is not remembered, it may readily be referred to in any of the standard handbooks. There are some constructions, however, with which the draftsman should be familiar, as they will occur more or less frequently in his work. The constructions in the chapter are given on this account and for the excellent practice they afford in the accurate use of instruments as well.

As an aid in recalling the names of various geometrical figures see Fig. 186 at the end of this chapter.

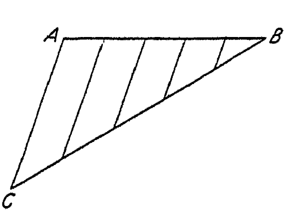


FIG. 129.—To divide a line.

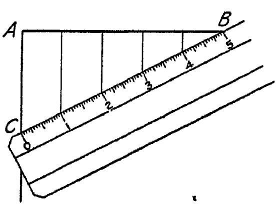


FIG. 130.—Scale method.

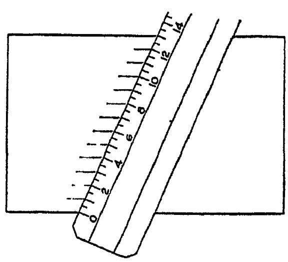


FIG. 131.—Scale method.

52. To Divide a Line—Geometrical Method.—Fig. 129. To divide a line AB into (say) five equal parts, draw any line BC of indefinite length, on it measure or step off five divisions of convenient length, connect the last point with A and, using triangles and straightedge as shown in Fig. 23, draw lines through the points parallel to CA intersecting AB.

Scale Method.—In the application of the foregoing principle the draftsman generally prefers the scale method: First draw a perpendicular AC

from A, then place a scale so that five convenient equal divisions are included between B and the perpendicular, as in Fig. 130. With triangle and T-square draw perpendiculars through the points marked, thus dividing the line AB as required. Figure 131 illustrates an application in laying off stair risers.

This method may be used for dividing a line into any series of proportional parts.

53. To Draw a Straight Line through a Point Parallel to Another Straight Line.—(When the method of Fig. 23 cannot be used) Fig. 132. With P

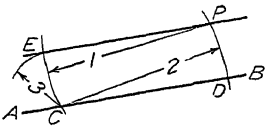


FIG. 132.

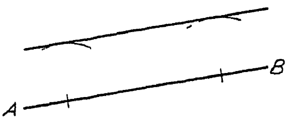


FIG. 133.

FIG. 134.

as center and a radius of sufficient length, draw an arc CE intersecting the line AB at C. With C as center and the same radius, draw the arc PD. With center C and radius DP, draw an arc intersecting CE at E. Then EP is the required line.

54. To Draw a Line Parallel to Another at a Given Distance from It. (1) *For Straight Lines.*—Fig. 133. With the given distance as a radius and two points on the given line as centers (as far apart as convenient), draw two arcs. A line tangent to these arcs will be the required line.

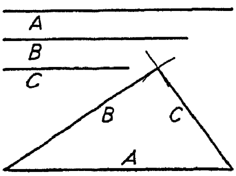


FIG. 135.—To construct a triangle.

(2) *For Curved Lines.*—Fig. 134. Draw a series of arcs with centers along the line. Draw tangents to these arcs with French curve. See Fig. 436.

55. To Construct a Triangle Having Given the Three Sides.—Fig. 135. Given the lengths A, B and C. Draw one side A in the desired position. With its ends as centers and radii B and C draw two intersecting arcs as shown. This construction is used extensively in developments by triangulation.

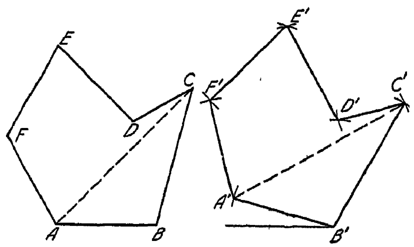


FIG. 136.—To transfer a polygon.

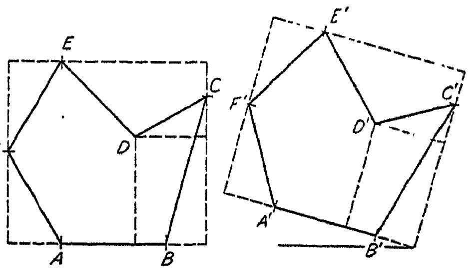


FIG. 137.—Box or offset method.

56. To Transfer a Polygon to a New Base.—Fig. 136. Given polygon $ABCDEF$ and new position of base $A'B'$. Consider each point as the vertex

of a triangle whose base is AB. With centers A' and B' and radii AC and BC, describe intersecting arcs, locating the point C'. Similarly with radii AD and BD locate point D'. Connect $B'C'$ and $C'D'$ and continue the operation, always using A and B as centers.

Box or Offset Method.—Fig. 137. Enclose the polygon in a rectangular "box." Draw the box on the new base (method of Fig. 24), locate the points $ABCEF$ on it and locate point D by rectangular coordinates as shown.

57. To Construct a Regular Hexagon. *Given the Distance across Corners AB. First Method.*—Fig. 138. Draw a circle on AB as a diameter. With the same radius and A and B as centers, draw arcs intersecting the circle and connect the points.

Second Method (without Compasses).—Draw lines with the 30°–60° triangle in the order shown in Fig. 139.

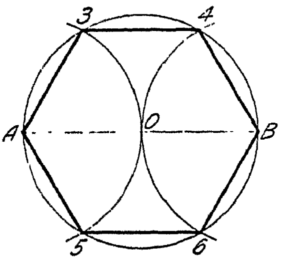


FIG. 138.—Hexagon.

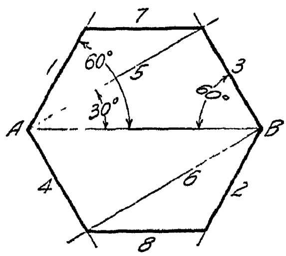


FIG. 139.—Hexagon.

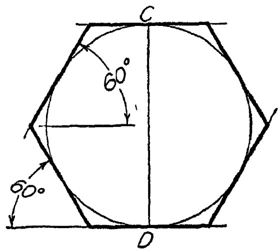


FIG. 140.—Hexagon.

Given the Distance across Flats.—The distance across flats is the diameter of the inscribed circle. Draw this circle and with the 30°–60° triangle draw tangents to it as in Fig. 140. See Fig. 373.

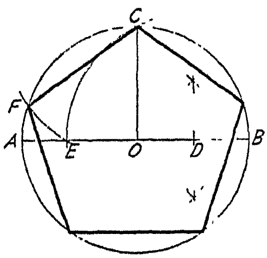


FIG. 141.—Pentagon.

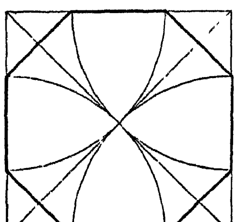


FIG. 142.—Octagon.

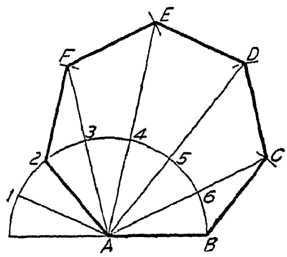


FIG. 143.—Polygon.

58. To Inscribe a Regular Pentagon in a Circle.—Fig. 141. Draw a diameter AB and a radius OC perpendicular to it. Bisect OB. With this point D as center and a radius DC, draw arc CE. With center C and radius CE, draw arc EF. CF is the side of the pentagon. Step off this distance around the circle with the dividers. Instead of using this geometrical method, most draftsmen prefer to guess at CF and divide the circle by trial as described in paragraph 13.

59. To Draw a Regular Octagon in a Square.—Fig. 142. Draw the diagonals of the square. With the corners of the square as centers and a

radius of half the diagonal, draw arcs intersecting the sides of the square and connect these points.

60. To Construct a Regular Polygon. *Given One Side.*—Fig. 143. Let the polygon have seven sides. With the side AB as a radius and A as center, draw a semicircle and divide it into seven equal parts. Through the second division from the left draw radial line $A2$. Through points 3, 4, 5, 6 extend radial lines as shown. With AB as radius and B as center cut line $A6$ at C. With C as center and same radius cut $A5$ at D, and so on at E and F. Connect the points *or,* after $A2$ is found, draw the circumscribing circle.

61. To Draw a Circle Arc through Three Given Points.—Fig. 144. Given the points A, B and C. The intersection of the perpendicular bisectors of lines AB and BC will be the center of the required circle.

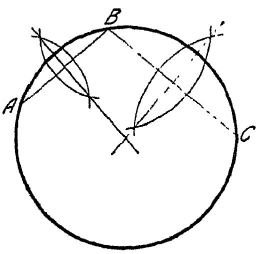


FIG. 144.—Circle through three points.

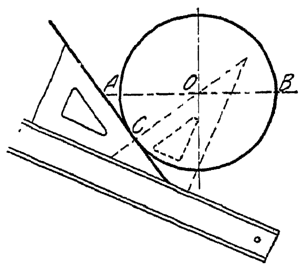


FIG. 145.—Drawing a tangent.

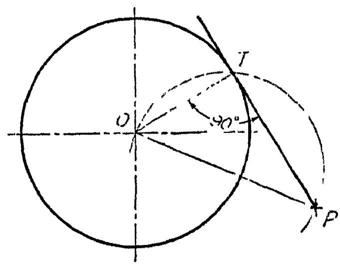


FIG. 146.—Tangent from point outside.

62. Tangents.—One of the most frequent geometrical operations in drafting is the drawing of tangents to circle arcs and of circle arcs tangent to straight lines or other circles. These should be constructed accurately and on pencil drawings that are to be inked or traced the points of tangency should be located by short cross marks to show the stopping points for the ink lines. The method of finding these points is indicated in the following constructions.

63. To Draw a Tangent to a Circle at a Point on the Circle.—Fig. 145. Given the arc ACB, to draw a tangent at the point C. Arrange a triangle in combination with the T-square (or another triangle) so that its hypotenuse passes through center O and point C. Holding the T-square firmly in place, turn the triangle about its square corner and move it until the hypotenuse passes through C; the required tangent then lies along the hypotenuse. (For small constructions, or with a large triangle, this may be done a little quicker by setting the hypotenuse of the triangle on the T-square as in Fig. 24 at B.)

64. To Draw a Tangent to a Circle from a Point Outside.—Fig. 146. Connect the point with the center of the circle. On this line OP as a diameter draw a semicircle. Its intersection with the given circle is the point of tangency. (Prove.)

65. To Draw a Tangent to Two Circles. *First Case.*—Fig. 147 (open belt). At center O draw a circle with a radius R_1 minus R_2. From P draw a tangent to this circle by the method of Fig. 146. Extend OT to T_1 and draw PT_2 parallel to OT_1. Joint T_1 and T_2.

Second Case. Fig. 148 (crossed belt). Draw OA and O_1B perpendicular to OO_1. From P where AB crosses OO_1 draw tangents as in Fig. 146.

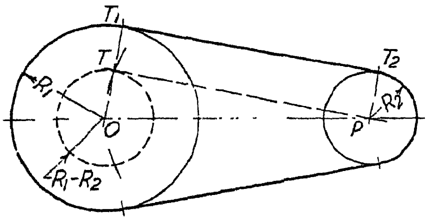


FIG. 147.—Open belt.

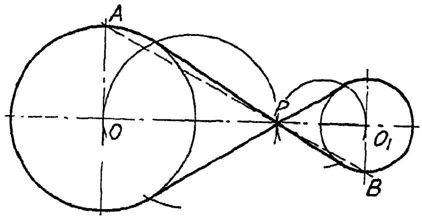


FIG. 148.—Crossed belt.

66. To Draw a Circle Tangent to Two Straight Lines.—Fig. 149. Given the lines AB and CD and radius R. A line parallel to AB at the distance R from it is the locus of the centers of all circles of radius R tangent to AB. Its intersection with a straight-line locus parallel to and at distance R from CD will be the center of the required arc. Find the points of tangency by drawing perpendiculars from O to AB and CD. Figure 150 is the same

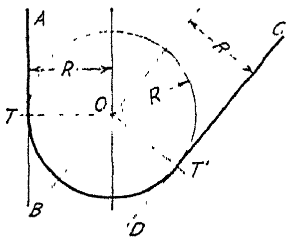


FIG. 149.—Tangent arc.

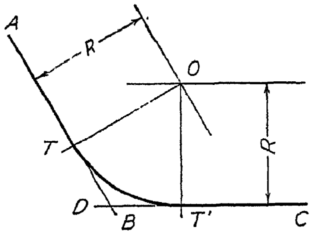


FIG. 150.—Tangent arc.

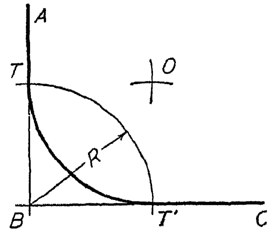


FIG. 151.—Tangent arc.

construction with an obtuse angle. For a right angle, Fig. 151, a quicker construction is to draw an arc of radius R with B as center, cutting AB and BC at T and T'. With T and T' as centers and same radius draw arcs intersecting at O, the center for the required arc.

67. To Draw a Circle of Radius R Tangent to a Given Circle and a Straight Line.—Fig. 152. Let AB be the given line and R_1 the radius of the given circle. Draw a line CD parallel to AB at a distance R from it. With O as a center and radius $R + R_1$, swing an arc intersecting CD at X, the desired center. The tangent point for AB will be on a perpendicular to AB from X; the tangent point for the two circles will be on a line joining their centers X and O. Note that when two circles are tangent to each other the point of tangency *must* be on a line through their centers.

68. To Draw a Circle of Radius R Tangent to Two Given Circles. *First Case.*—Fig. 153. For this case the centers of the given circles are outside the required circle. Let R_1 and R_2 be the radii of the given circles having centers O and P respectively. With O as a center and a radius $R + R_1$, describe an arc. With P as a center and a radius $R + R_2$, swing another arc intersecting the first arc at Q, which is the center sought. Mark the tangent points in line with OQ and QP.

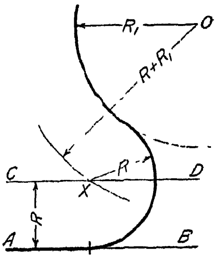


FIG. 152.—Tangent arc.

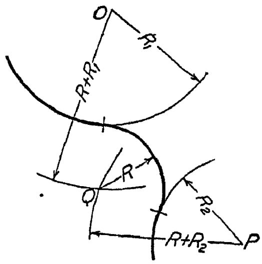


FIG. 153.—Tangent arc.

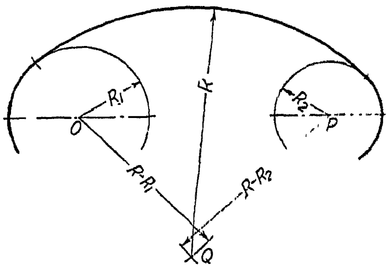


FIG. 154.—Tangent arc.

Second Case.—Fig. 154. For this case the centers of the given circles are inside the required circle. With O and P as centers and radii $R - R_1$ and $R - R_2$, describe arcs intersecting at the required center Q.

69. To Draw a Reverse or Ogee Curve.—Fig. 155. Given two parallel lines AB and CD. Join B and C by a straight line. Erect perpendiculars at B and C. Any arcs tangent to lines AB and CD at B and C must have their centers on these perpendiculars. On the line BC assume point E, the point through which it is desired that the curve shall pass. Bisect BE

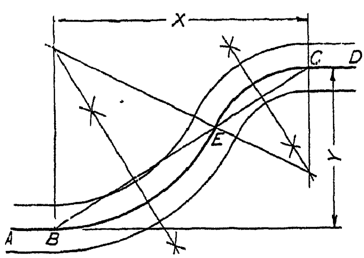


FIG. 155.—Ogee curve.

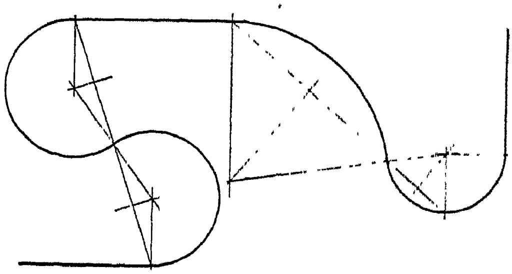
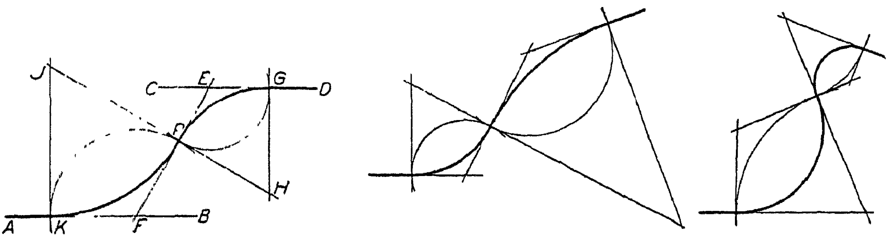


FIG. 156.—Ogee applications.

and EC by perpendiculars. Any arc to pass through B and E must have its center somewhere on the perpendicular from the middle point. The intersection therefore of these perpendicular bisectors with the first two perpendiculars will be the centers for arcs BE and EC. This line might be the center line for a curved road or pipe. The construction may be checked by drawing the line of centers, which *must* pass through E. Figure 156 illustrates the principle of reverse-curve construction in various combinations.

70. To Draw a Reverse Curve Tangent to Two Lines and to a Third Secant Line at a Given Point.—Fig. 157*A*, *B* and *C*. Given two lines *AB* and *CD* cut by the line *EF* at points *E* and *F*. Through a given point *P* on *EF* draw a perpendicular *JH* to *EF*. With *E* as a center and radius *EP* intersect *CD* at *G*. Draw a perpendicular from *G* intersecting *JH* at *H*. With *F* as center and radius *FP* intersect *AB* at *K*. Draw a perpendicular to *AB* from *K* intersecting *JH* at *J*. *H* and *J* will be centers for arcs tangent to the three lines.



A B C

FIG. 157.—Reverse curve tangent to three lines.

71. To Lay Off on a Straight Line the Approximate Length of a Circle Arc.—Fig. 158. Given the arc *AB*. At *A* draw the tangent *AD* and chord *BA* produced. Lay off *AC* equal to half the chord *AB*. With center *C* and radius *CB* draw an arc intersecting *AD* at *D*; then *AD* will be equal in length to the arc *AB* (very nearly).[1] If the given arc is between 45°

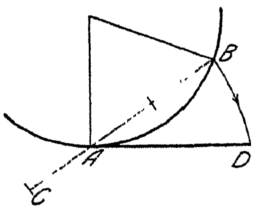


FIG. 158.—Length of arc.

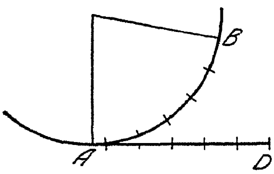


FIG. 159.—Length of arc.

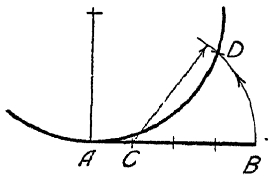


FIG. 160.—Length on arc.

and 90° a closer approximation will result by making *AC* equal to the chord of half the arc instead of half the chord of the arc.

The usual way of rectifying an arc is to set the dividers to a space small enough to be practically equal in length to the corresponding arc. Starting at *B* step along the arc to the point nearest *A* and without lifting the dividers step off the same number of spaces on the tangent, as shown in Fig. 159.

72. To Lay Off on a Given Circle the Approximate Length of a Straight Line.—Fig. 160. Given the line *AB*, tangent to the circle at *A*. Lay off *AC*

[1] In this (Professor Rankine's) solution, the error varies as the fourth power of the subtended angle. For 60° the line will be $\frac{1}{900}$ part short, while at 30° it will be only $\frac{1}{14400}$ part short.

equal to one-fourth AB. With C as a center and radius CB draw an arc intersecting the circle at D. The arc AD is equal in length to AB (very nearly).[1] If arc AD is greater than 60° solve for one-half AB.

73. Conic Sections.—In cutting a right circular cone (a cone of revolution) by planes at different angles, four curves called *conic sections* are obtained, Fig. 161. These are the *circle,* cut by a plane perpendicular to the axis; the *ellipse,* cut by a plane making a greater angle with the axis than the elements do; the *parabola,* cut by a plane making the same angle with the axis as the elements do; the *hyperbola,* cut by a plane making a smaller angle than the elements do. These curves are studied mathematically in analytic geometry but may be drawn without a knowledge of their equations by knowing something of their characteristics.

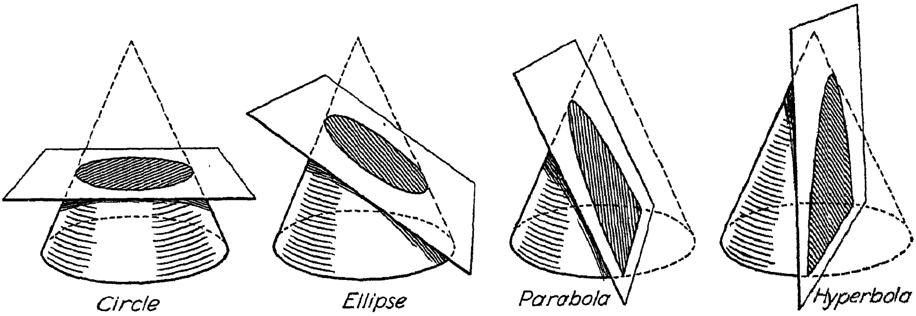


FIG. 161.—The conic sections.

74. The Ellipse.—Fig. 162. An ellipse is the plane curve generated by a point moving so that the sum of its distances from two fixed points (F_1, F_2), called the "focuses," is a constant equal to the long diameter, or major axis AB.

The minor axis or short diameter DE is the line through the center perpendicular to the major axis. The focuses may be determined by cutting the major axis with an arc having its center at an end of the minor axis and radius equal to one-half the major axis.

Aside from the circle the ellipse is met with in practice much more often than any of the other conics, and draftsmen should be able to construct it readily, hence several methods are given for its construction, both as a true ellipse and as an approximate curve made by circle arcs. In the great majority of cases when this curve is required, its long and short diameters, that is, its major and minor axes, are known.

75. Ellipse—Pin and String Method.—This well-known method, sometimes called the "gardener's ellipse," is often used for large work and is based on the definition of the ellipse. Drive pins at the points D, F_1 and F_2, Fig. 162, and tie an inelastic thread or cord tightly around the three pins. If the pin D is removed and a marking point moved in the loop, keeping the cord taut, it will describe a true ellipse.

[1] *Ibid.*

76. Ellipse—Trammel Method.—Fig. 163. On the straight edge of a strip of paper, thin cardboard or sheet of celluloid, mark the distance *ao* equal to one-half the major axis and *do* equal to one-half the minor axis. If the strip is moved, keeping *a* on the minor axis and *d* on the major axis, *o* will

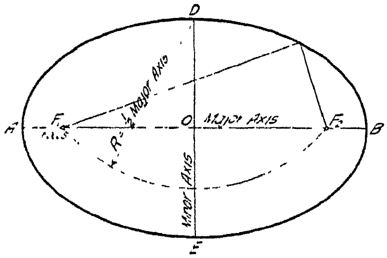


FIG. 162.—The ellipse.

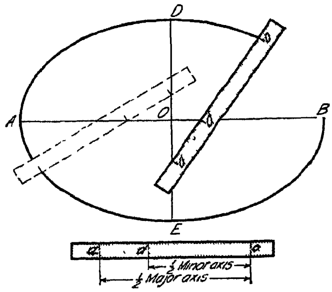


FIG. 163.—Trammel method.

give points on the ellipse. This method will be found very convenient, as no construction is required, but for accurate results great care must be taken to keep the points *a* and *d* exactly on the axes. The ellipsograph, Fig. 1033, is constructed on the principle of this method.

77. Conjugate Diameters.—Any line through the center of an ellipse may serve as one of a pair of conjugate diameters. A property of conjugate diameters, or conjugate axes, is that each is parallel to the tangents to the curve at

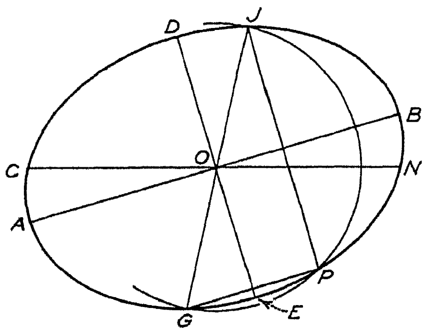


FIG. 164.—Conjugate axes.

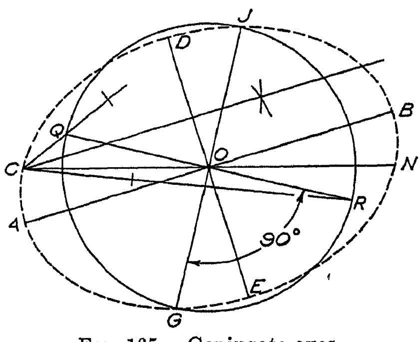


FIG. 165.—Conjugate axes.

the extremities of the other. Either one of a pair of conjugate diameters bisects all the chords parallel to the other.

To Determine the Major and Minor Axes of a Given Ellipse, a Pair of Conjugate Axes Being Given. First Method.—Fig. 164. Given the conjugate axes *CN* and *JG*. With center *O* and radius *OJ* draw a semicircle intersecting the ellipse at *P*. The major and minor axes will be parallel to the chords *GP* and *JP*, respectively.

Second Method When the Curve Is Not Given.—Fig. 165. Given the conjugate axes *CN* and *JG*. With center *O* and radius *OJ* describe a circle and draw the diameter *QR* at right angles to *JG*. Bisect the angle *QCR*.

The major axis will be parallel to this bisector and equal in length to $CR + CQ$. The length of the minor axis will be $CR - CQ$.

78. Ellipse—Parallelogram Method.—Figs. 166 and 167. This method may be used with either the major and minor axes or with any pair of conjugate diameters. On the diameters construct a parallelogram. Divide AO into any number of equal parts and AG into the same number of equal

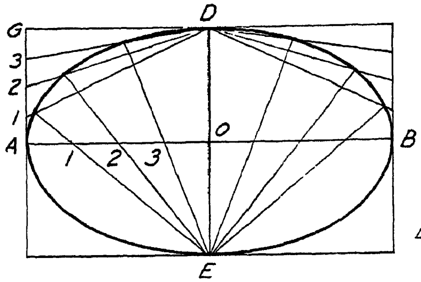


FIG. 166.—Parallelogram method.

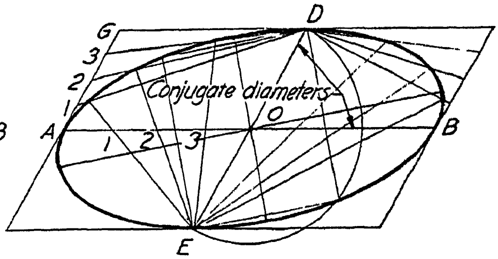


FIG. 167.—Parallelogram method.

parts, numbering points from A. Through these points draw lines from D and E as shown. Their intersections will be points on the curve.

79. Ellipse—Concentric-circle Method.—Fig. 168. This is perhaps the most accurate method for determining points on the curve. On the two principal diameters, which intersect at O, describe circles. From a number of points on the outer circle, as P and Q, draw radii OP, OQ, etc., intersecting the inner circle at P', Q', etc. From P and Q draw lines parallel to OD, and

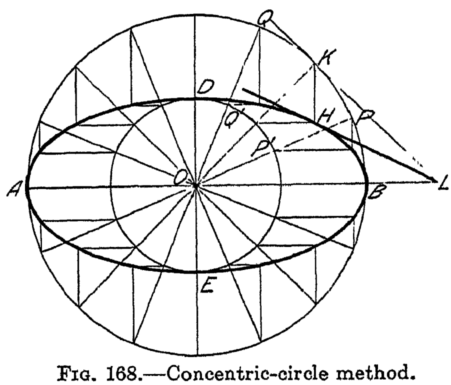


FIG. 168.—Concentric-circle method.

from P' and Q' lines parallel to OB. The intersection of the lines through P and P' gives one point on the ellipse, the intersection of the lines through Q and Q' another point, and so on. For accuracy the points should be taken closer together toward the major axis. The process may be repeated in each of the four quadrants and the curve sketched in lightly freehand; or one quadrant only may be constructed and the remaining three repeated by marking the French curve.

80. To Draw a Tangent to an Ellipse. (1) *At a Point P on the Curve.*—Fig. 169. Draw lines from the point to the focuses. The line bisecting the exterior angle of these focal radii is the required tangent.

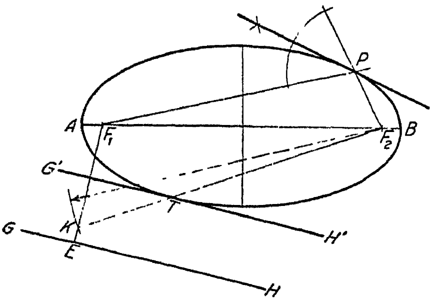


FIG. 169.—Tangents.

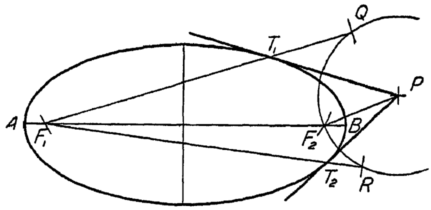


FIG. 170.—Tangent from point outside.

When the ellipse has been drawn by the concentric-circle method, Fig. 168, a tangent at any point H may be drawn by dropping a perpendicular from the point to the outer circle at K and drawing the auxiliary tangent KL to the outer circle, cutting the major axis at L. From L draw the required tangent LH.

(2) *From a Point Outside.* Fig. 170. Find the focuses F_1 and F_2. With given point P and a radius PF_2 draw the arc RF_2Q. With F_1 as center and a radius AB strike an arc cutting this arc at Q and R. Connect QF_1 and RF_1. The intersections of these lines with the ellipse at T_1 and T_2 will be the tangent points of tangents to the ellipse from P. (Prove.)

(3) *Parallel to a Given Line GH.*—Fig. 169. Draw F_1E perpendicular to GH. With F_2 as center and radius AB draw an arc cutting F_1E at K. The line F_2K cuts the ellipse at the required point of tangency T, and the required tangent passes through T parallel to GH.

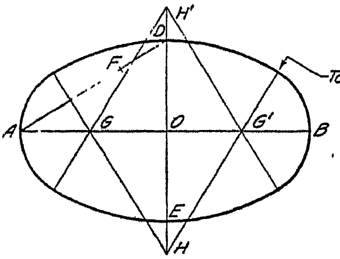


FIG. 171.—Approximate ellipse.

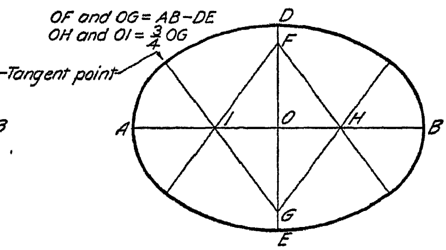


FIG. 172.—Approximate ellipse.

81. Approximate Four-center Ellipse.—Fig. 171. Join A and D. Lay off DF equal to AO minus DO. Bisect AF by a perpendicular crossing AO at G and intersecting DE produced (if necessary) at H. Make OG' equal to OG, and OH' equal to OH. Then G, G', H and H' will be centers for four tangent circle arcs forming a curve approximating the shape of an ellipse.

Another method is shown in Fig. 172. This should be used only when the minor axis is at least two-thirds the length of the major axis.

82. Approximate Eight-center Ellipse.—Fig. 173. When a closer approximation is desired, the eight-centered ellipse, the upper half of which is known in masonry as the "five-centered arch," may be constructed. Draw the rectangle $AFDO$. Draw the diagonal AD and the line from F perpendicular to it, intersecting the extension of the minor axis at H. Lay off OK equal to OD and on AK as a diameter draw a semicircle intersecting the extension of the minor axis at L. Make OM equal to LD. With center H and radius HM draw the arc MN. From A along AB lay off AQ equal to OL. With P as center and radius PQ draw an arc intersecting the arc MN at N; then P, N and H are centers for one quarter of the eight-centered approximate ellipse. This method is based on the principle that the radius of curvature at the end of the minor axis is the third proportional to the semiminor and semimajor axes, and, inversely, at the end of the major axis is the third proportional to the semimajor and semiminor axes. The intermediate radius found is the mean proportional between these two radii.

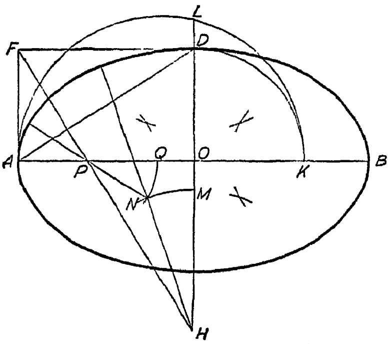


Fig. 173.—Approximate ellipse.

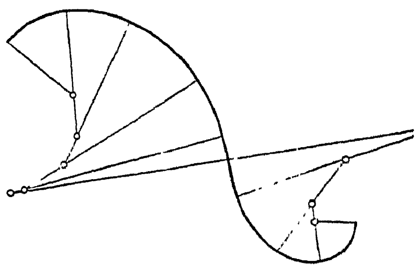


Fig. 174.—Curve made with circle arcs.

It should be noted that an ellipse is changing its radius of curvature at every successive point and that these approximations are therefore not ellipses, but simply curves of the same general shape and, incidentally, not nearly so pleasing in appearance.

83. Any noncircular curve may be approximated by tangent circle arcs, as follows: select a center by trial, draw as much of an arc as will practically coincide with the curve and then, changing the center and radius, draw the next portion, remembering always that, *if arcs are to be tangent, their centers must lie on the common normal at the point of tangency.* Draftsmen sometimes prefer to ink curves in this way rather than to use irregular curves. Figure 174 illustrates the construction.

84. The Parabola.—The parabola is a plane curve generated by a point so moving that its distance from a fixed point, called the *focus*, is always equal to its distance from a straight line, called the *directrix*. Among its practical applications are included searchlights and parabolic reflectors, some loudspeakers, road sections, certain bridge arches, etc.

When the focus F and the directrix AB are given, Fig. 175, draw the axis through F perpendicular to AB. Through any point D on the axis draw a line parallel to AB. With the distance DO as a radius and F as a center draw an arc intersecting the line, thus locating a point P on the curve. Repeat the operation as many times as needed.

To Draw a Tangent at Any Point P.—Draw PQ parallel to the axis; and bisect the angle FPQ.

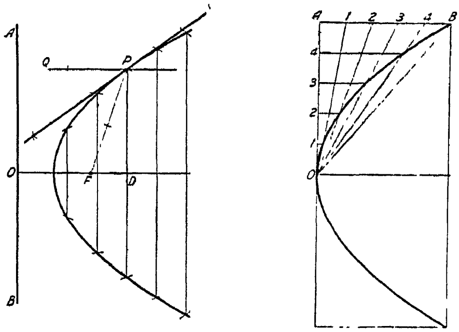


Fig. 175. Fig. 176.
Methods of drawing the parabola.

85. Parabola—Parallelogram Method.—Usually when a parabola is required, the dimensions of enclosing rectangle, that is, the width and depth of the parabola (or span and rise) are given, as in Fig. 176. Divide OA and AB into the same number of equal parts. From the divisions on AB draw lines converging at O. The intersections of these with the lines from the corresponding divisions on OA that are drawn parallel to the axis will be points on the curve.

86. Parabola—Offset Method.—Given the enclosing rectangle, the parabola, Fig. 177, may be plotted by computing the offsets from the line OA. These offsets vary in length as the square of their distances from O. Thus if OA is divided into four parts, DD' will be one-sixteenth of AA'; CC' (since it is twice as far from O as DD' is) will be four-sixteenths of AA', and BB' nine-sixteenths. If OA had been divided into five parts the relations would be $\frac{1}{25}$, $\frac{4}{25}$, $\frac{9}{25}$, $\frac{16}{25}$, the denominator being in each case the square of the number of divisions. This method is the one generally used by civil engineers in drawing parabolic arches.

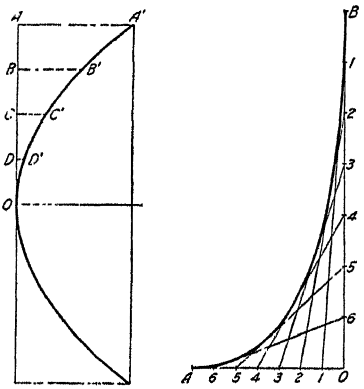


Fig. 177. Fig. 178.
Methods of drawing the parabola.

87. Parabolic Envelope.—Fig. 178. This method of drawing a pleasing curve is often used in machine design. Divide OA and OB into the same number of equal parts. Number the divisions from O and B and connect corresponding numbers. The tangent curve will be a portion of a parabola, but a parabola whose axis is not parallel to either ordinate.

88. The Hyperbola.—The hyperbola is a plane curve generated by a point moving so that the difference of its distances from two fixed points,

called the "focuses," is a constant. (Compare this definition with that of the ellipse.)

To draw a hyperbola when the focuses F_1F_2 and the transverse axis AB (constant difference) are given, Fig. 179. With F_1 and F_2 as centers and any radius greater than F_1B, as F_1P, draw arcs. With the same centers and radius F_1P minus AB strike arcs intersecting these arcs, giving points on the curve.

To Draw a Tangent at Any Point P, bisect the angle F_1PF_2.

89. Equilateral Hyperbola.—The case of the hyperbola of commonest practical interest to the engineer is the equilateral or rectangular hyperbola referred to its asymptotes. With it the law $pv = c$, connecting the varying pressure and volume of a portion of steam or gas, can be graphically represented.

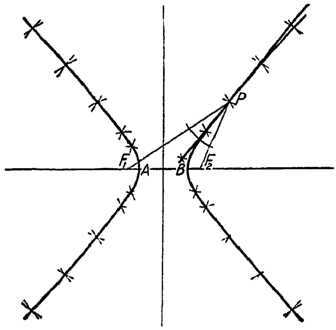


FIG. 179.—Hyperbola.

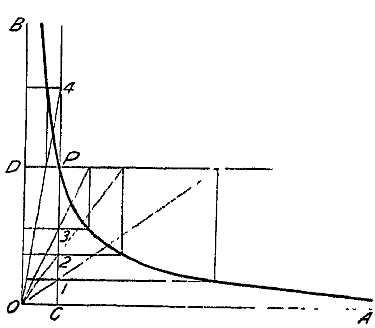


FIG. 180.—Equilateral hyperbola.

To Draw the Equilateral Hyperbola.—Fig. 180. Let OA and OB be the asymptotes of the curve, and P any point on it (this might be the point of cutoff on an indicator diagram). Draw PC and PD. Mark any points 1, 2, 3, etc., on PC and through these points draw a system of lines parallel to OA and a second system through the same points converging to O. From the intersections of these lines of the second system with PD extended, draw perpendiculars to OA. The intersections of these perpendiculars with the corresponding lines of the first system give points on the curve.

90. Cycloidal Curves.—A cycloid is the curve generated by the motion of a point on the circumference of a circle rolled in a plane along a straight line. If the circle is rolled on the outside of another circle, the curve generated is called an "epicycloid"; if rolled on the inside it is called a "hypocycloid." These curves are used in drawing the cycloid system of gear teeth.

To Draw a Cycloid.—Fig. 181. Divide the rolling circle into a convenient number of parts (say eight) and lay off on the tangent AB the rectified length of the circumference, using these divisions. Draw through C the line of centers CD and project the division points up to this line by perpendiculars to AB. About these points as centers draw circles representing different

positions of the rolling circle and project in order the division points of the original circle across to these circles. The intersections thus determined will be points on the curve. The epicycloid and hypocycloid may be drawn similarly, as illustrated in Fig. 182.

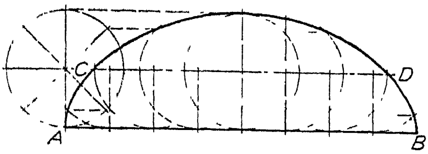


FIG. 181.—Cycloid.

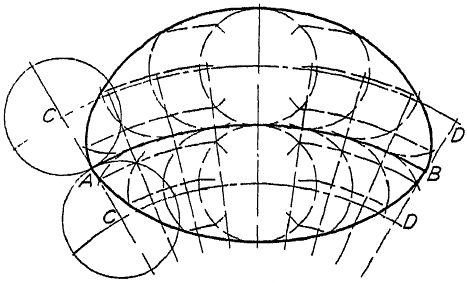


FIG. 182.—Epicycloid and hypocycloid.

91. The Involute.—An involute is the spiral curve traced by a point on a taut cord unwinding from around a polygon or circle. Thus the involute of any polygon may be drawn by extending its sides, as in Fig. 183, and with the corners of the polygon as successive centers drawing arcs terminating on the extended sides.

In drawing spirals in design, as, for example, of bent ironwork, the easiest way is to draw it as the involute of a square as in Fig. 63.

A circle may be conceived as a polygon of an indefinite number of sides. Thus to draw the involute of a circle, Fig. 184, divide it into a convenient

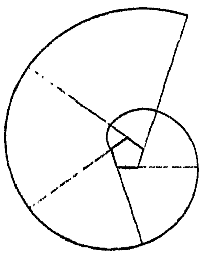


FIG. 183.—Involute of a pentagon.

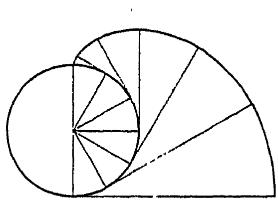


FIG. 184.—Involute of a circle.

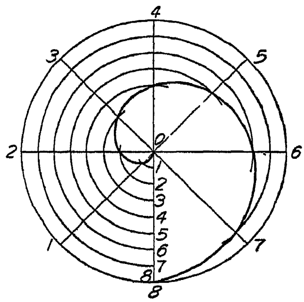


FIG. 185.—Spiral of Archimedes.

number of parts, draw tangents at these points, lay off on these tangents the rectified lengths of the arcs from point of tangency to the starting point and connect the points by a smooth curve. It is evident that the involute of a circle is the limiting case of the epicycloid, the rolling circle of which is of infinite diameter. The involute of the circle is the basis for the involute system of gearing.

92. The Spiral of Archimedes.—The spiral of Archimedes is the plane curve generated by a point moving uniformly along a straight line while the line revolves about a fixed point with uniform angular velocity.

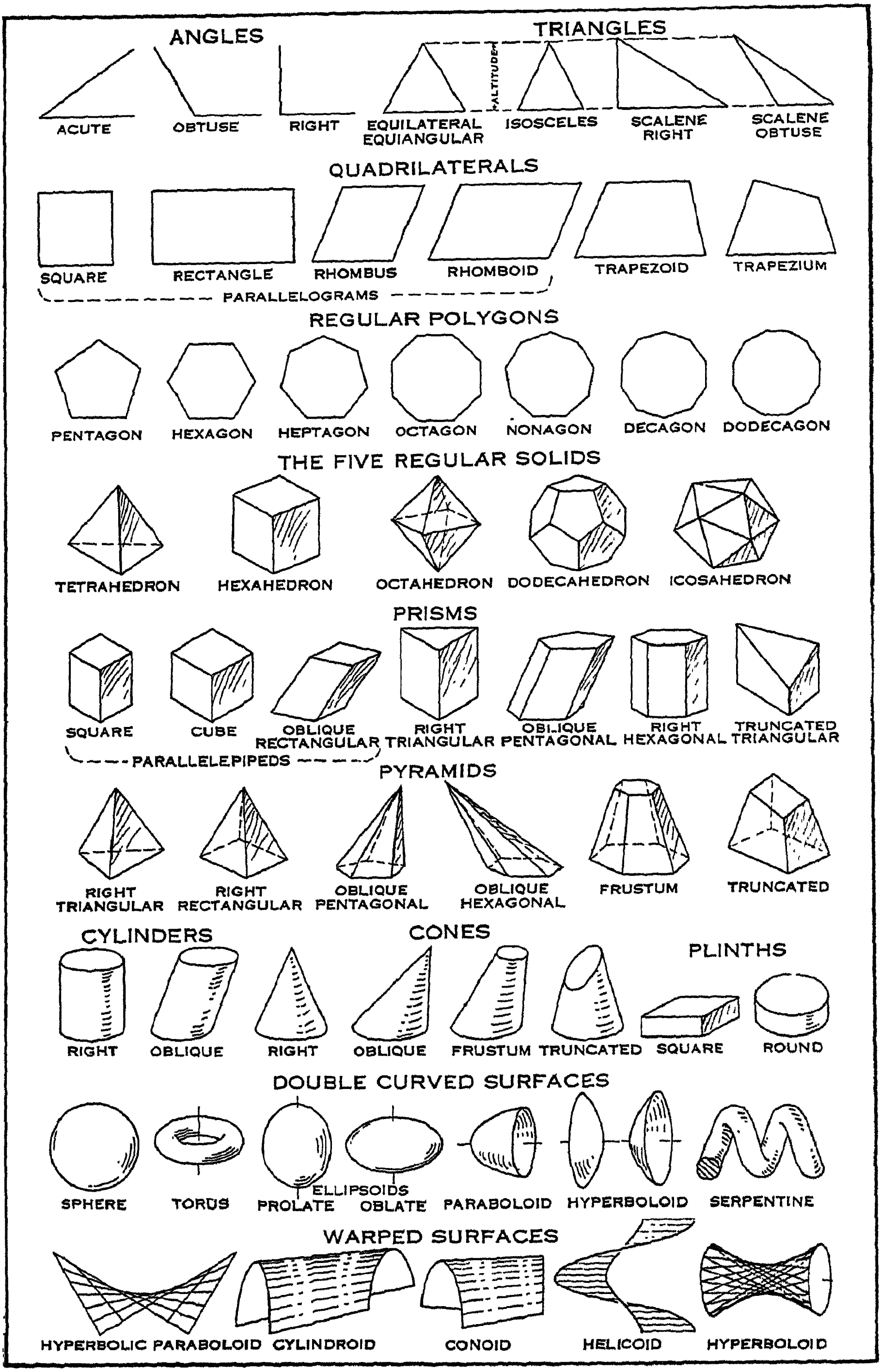


FIG. 186.—A page of geometric shapes.

To draw a spiral of Archimedes that makes one turn in a given circle, Fig. 185, divide the circle into a number of equal parts, drawing the radii and numbering them. Divide the radius *O*-8 into the same number of equal parts, numbering from the center. With *O* as a center, draw concentric arcs intersecting the radii of corresponding numbers and draw a smooth curve through these intersections. The Archimedean spiral is the curve of the heart cam used for converting uniform rotary motion into uniform reciprocal motion.

PROBLEMS

93. To be of value both as drawing exercises and as solutions, geometrical problems should be worked very accurately. The pencil must be kept very sharp, and comparatively light lines must be used. A point should be located by two intersecting lines, and the length of a line should be indicated by short dashes across the given line. The following problems are dimensioned to fit in a space of not over 5″ × 7″, except as noted. Thus either one or two may be drawn on a standard 8½″ × 11″ sheet, and either two or four on an 11″ × 17″ sheet.

1. Near the center of the space draw a horizontal line 4½″ long. Divide it into seven equal parts by the method of Fig. 130.

2. Draw a vertical line 1″ from left edge of space and 3⅞″ long. Divide it into parts proportional to 1, 3, 5 and 7.

3. Construct a polygon as shown in Fig. 187, drawing the line *AK* horizontally, of indefinite length ⅝″ above bottom of space. From *A* draw and measure *AB*. Proceed

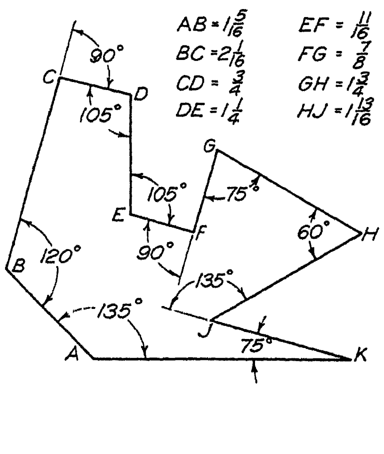


FIG. 187.—Irregular polygon.

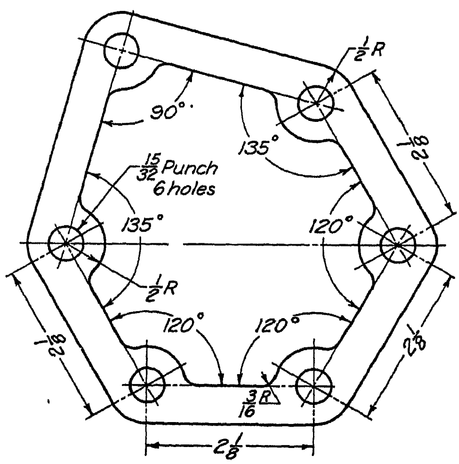


FIG. 188.—Gasket.

in the same way for the remaining sides. The angles may all be obtained by proper combinations of the two triangles. See Figs. 21 and 22.

4. Draw line *AK* making an angle of 15° with the horizontal. With this line as a base transfer the polygon of Fig. 187.

5. Draw gasket, Fig. 188, in position shown.

6. Draw gasket, Fig. 188, turning it so that its two parallel sides are horizontal.

7. Draw a regular hexagon having a distance across corners of 4″.

8. Draw a regular hexagon, short diameter $3\frac{3}{8}$″.

9. Draw a regular dodecagon, short diameter $3\frac{3}{8}$″.

10. Construct an ogee curve joining two parallel lines AB and AC as in Fig. 155, making $X = 4''$, $Y = 2\frac{1}{2}''$ and $BE = 3''$. Consider this as the center line for a rod $1\frac{1}{4}''$ diameter and draw the rod.

11. Make a drawing of an ogee pipe bend from data in Fig. 189.

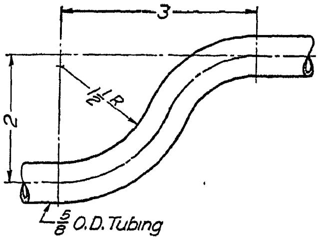


FIG. 189.—Pipe bend.

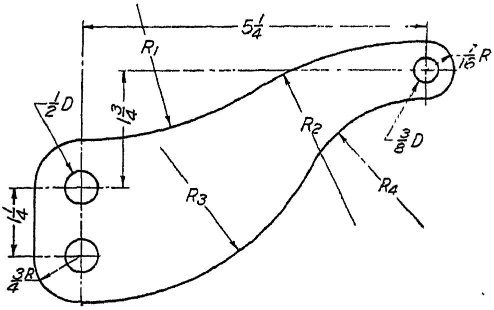


FIG. 190.—Bracket.

12. Make the contour view of the bracket shown in Fig. 190. In the upper ogee curve the radii R_1 and R_2 are equal. In the lower one, R_3 is twice R_4.

13. Draw an arc of a circle having a radius of $3\frac{13}{16}''$, with its center $\frac{1}{2}''$ from top of space and $1\frac{1}{2}''$ from left edge. Find the length of an arc of 60° by construction; compute the length arithmetically and check the result.

Tangent Problems

These problems are given for practice in the accurate joining of tangent lines. Read carefully paragraphs 63 to 69 before beginning. Locate centers for all circle arcs geometrically. If inked, ink outlines and center lines only.

14. A *gasket*, Fig. 191. Outside diameter 4″. Inside diameter $2\frac{3}{4}''$. Two $\frac{3}{4}''$ holes, 5″ center to center. Ears $\frac{3}{4}''$ radius, 1″ fillets. Mark tangent points in pencil, as in Fig. 153.

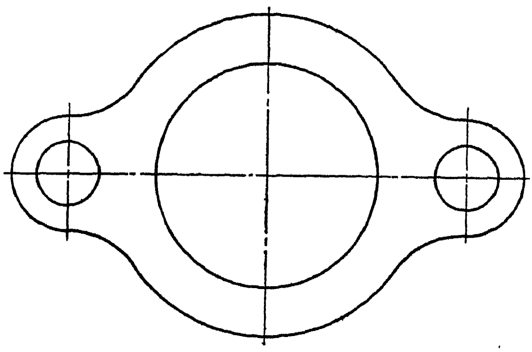


FIG. 191.—Gasket.

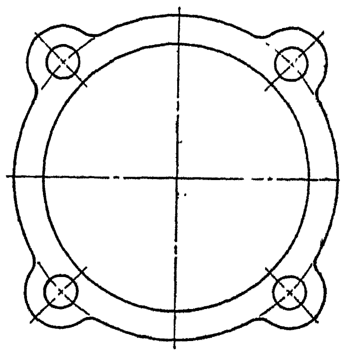


FIG. 192.—Shim.

15. A *shim*, Fig. 192. Outside diameter 4″. Inside diameter $3\frac{5}{32}''$. Holes $\frac{13}{32}''$. Ears $\frac{7}{16}''$ radius, $\frac{3}{16}''$ fillets. Draw center lines and on them measure and mark radii for given diameters. Mark all tangent points in pencil, as in Fig. 153.

16. Front view of a *star knob*, Fig. 193. Radius of circumscribing circle $2\frac{3}{8}''$. Diameter of hub $2\frac{1}{2}''$. Diameter of hole $\frac{3}{4}''$. Radius at points $\frac{3}{8}''$. Radius of fillets $\frac{3}{8}''$. Mark tangent points in pencil.

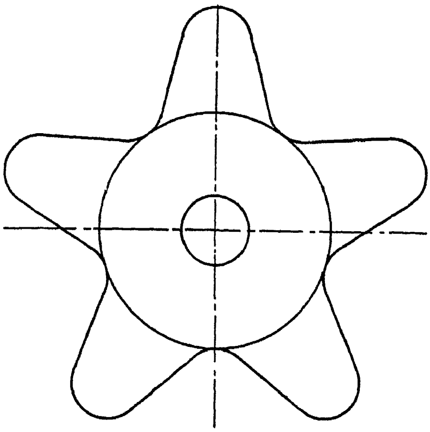


FIG. 193.—Star knob.

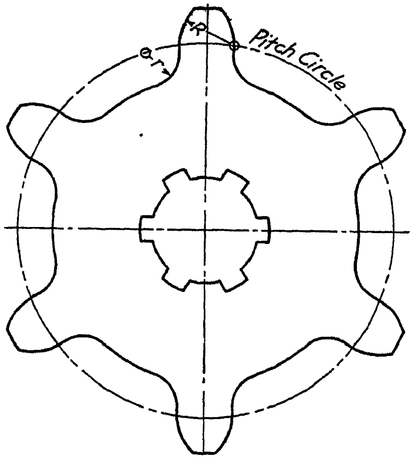


FIG. 194.—Sprocket.

17. Front view of a *sprocket*, Fig. 194. Outside diameter $4\frac{3}{4}''$, pitch diameter $4''$, root diameter $3\frac{1}{4}''$, bore $1\frac{1}{4}''$. Thickness of tooth at pitch line is $\frac{9}{16}''$. Splines $\frac{1}{4}''$ wide by $\frac{1}{8}''$ deep. Mark tangent points in pencil.

18. Front view of a *fan*, Fig. 195. Draw full size to dimensions given ($9'' \times 9''$ space).

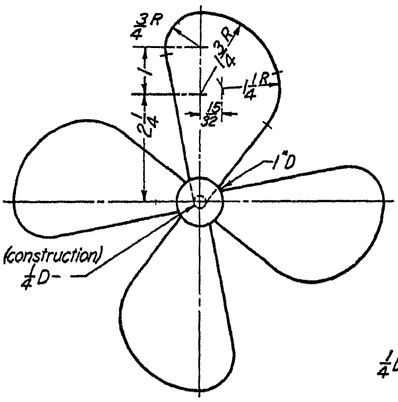


FIG. 195.—Fan.

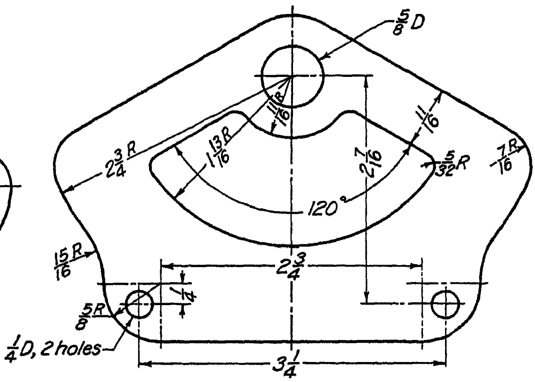


FIG. 196.—Level plate.

19. Front view of a *level plate*, Fig. 196, full size.

20. Front view of an *eyelet*, Fig. 197. Draw to dimensions given ($5'' \times 8''$ space).

21. Front view of a *stamping*, Fig. 198. Draw to dimensions given ($5'' \times 9''$ space).

22. Front view of a *cam*, Fig. 199.

23. Front view of a drawn-metal *fan base*, Fig. 200. The curve profile is a parabolic envelope. Refer to Fig. 178.

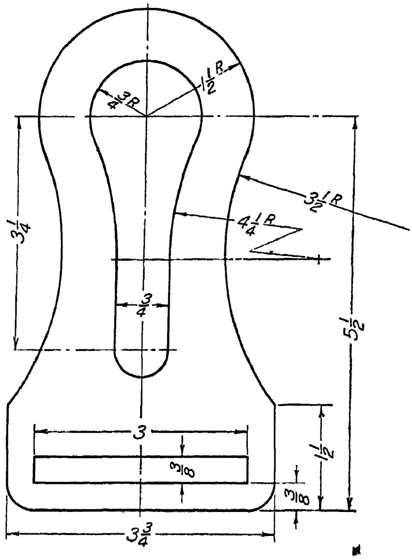


FIG. 197.—Eyelet.

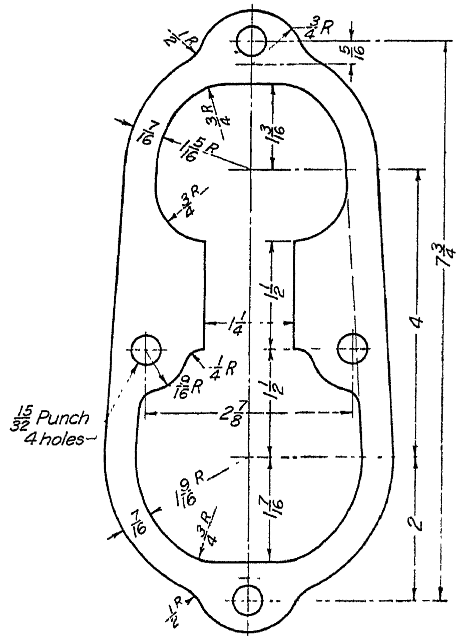


FIG. 198.—Stamping.

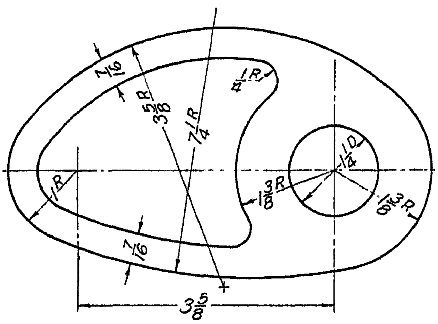


FIG. 199.—Cam.

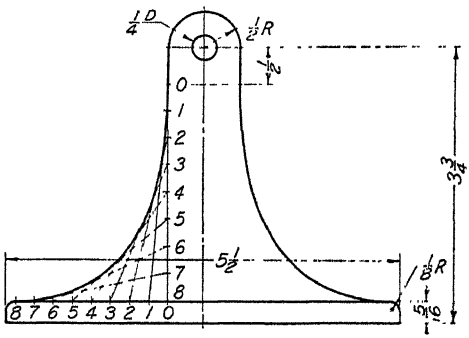


FIG. 200.—Fan base.

Curve Problems

In locating a curve the number of points to be determined will depend upon the size of the curve and the rate of change of curvature. More points should be found on the sharp turns. For most of the following problems, points may average about 1/4 inch apart.

24. Draw an ellipse having a major axis of 4½″ and minor axis of 3″, using the trammel method as explained in paragraph 76.

25. Draw an ellipse having a major axis of 4⅝″ and minor axis of 1½″, using the concentric-circle method as explained in paragraph 79.

26. Draw an ellipse on a major axis of 4″. One point on the ellipse is 1½″ to the left of the minor axis and ⅞″ above the major axis.

27. Draw an ellipse whose minor axis is 2³⁄₁₆″ and distance between focuses is 3¼″. Draw a tangent at a point 1⅜″ to the right of the minor axis.

28. Draw an ellipse, major axis 4″. A tangent to the ellipse intersects the minor axis $1\frac{3}{4}''$ from the center, at an angle of 60°.

29. Draw a five-centered arch with a span of 5″ and a rise of 2″. Refer to paragraph 82.

30. Draw an ellipse having conjugate axes of $4\frac{3}{4}''$ and $2\frac{3}{4}''$ making an angle of 75° with each other. Determine the major and minor axes.

31. Draw the major and minor axes for an ellipse having a pair of conjugate diameters 60° apart, one horizontal and $6\frac{1}{4}''$ long, the other $3\frac{1}{4}''$ long.

32. Draw a parabola, axis vertical, in a rectangle 4″ × 2″.

33. Draw a parabolic arch, with 6″ span and $2\frac{1}{2}''$ rise, by the offset method, dividing the half span into eight equal parts.

34. Draw an equilateral hyperbola passing through a point P, $\frac{1}{2}''$ from OB and $2\frac{1}{2}''$ from OA, reference letters corresponding to Fig. 180.

35. Draw two turns of the involute of a pentagon whose circumscribed circle is $\frac{1}{2}''$ in diameter.

36. Draw one-half turn of the involute of a circle $3\frac{1}{4}''$ in diameter whose center is 1″ from the left edge of space. Compute the length of the last tangent and compare with the measured length.

37. Draw a spiral of Archimedes making one turn in a circle 4″ in diameter.

38. Draw the cycloid formed by a rolling circle 2″ in diameter. Use 12 divisions.

39. Draw the epicycloid formed by a 2″-diameter circle rolling on a 15″-diameter directing circle. Use 12 divisions.

40. Draw the hypocycloid formed by a 2″-diameter circle rolling inside a 15″-diameter directing circle. Use 12 divisions.

CHAPTER VI

THE THEORY OF PROJECTION DRAWING

94. The previous chapters have been preparatory to the real subject of engineering drawing as a language. In Chap. I attention was directed to the difference between the representation of an object by the artist to convey certain impressions or emotions and the representation by the engineer to convey information. The full information required from the engineer includes the description of the *shape* of the object and the specification of the *size* of every detail in it. In this chapter we are concerned with the different methods of describing the *shape*.

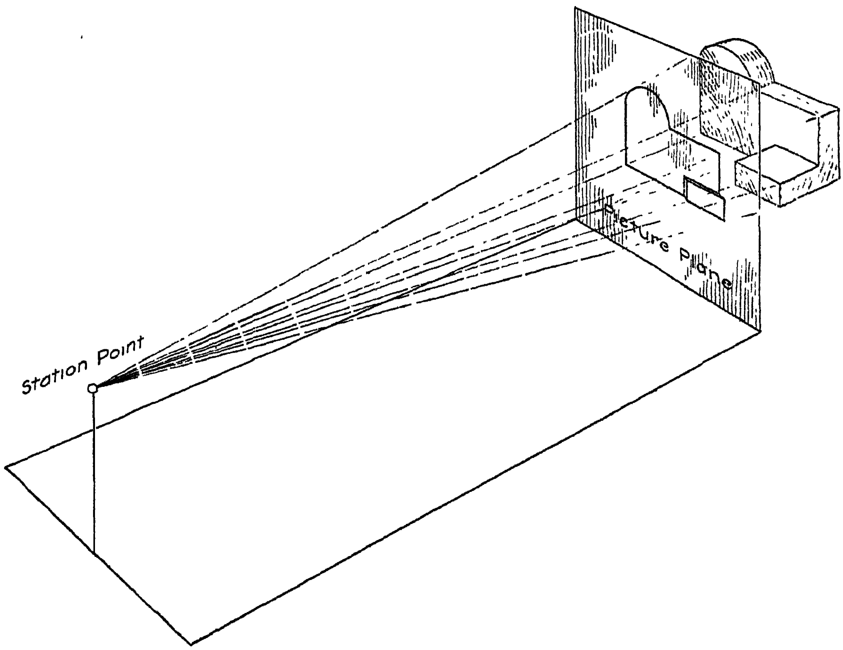


FIG. 201.—Perspective projection.

If an ordinary object is looked at from some particular station point one may usually get a good idea of its shape because (1) generally more than one side is seen, (2) the light and shadow on it tell something of its configuration and (3) since it is looked at with both eyes there is a stereoscopic effect which aids in judging shapes and dimensions. In technical drawing the third point is never considered, but the object is represented as if seen with one eye; and only in special cases is the effect of light and shadow rendered. In general we have to do with outline alone.

If a transparent plane is imagined as set up between an object and the station point of an observer's eye, Fig. 201, the intersection of this plane with the rays formed by lines of sight from the eye to all points of the object will give a picture which will be practically the same as the image formed in the eye of the observer. Drawing made on this principle is known as "perspective drawing" and is the basis of all artists' work. In a technical way it is used chiefly by architects in making preliminary sketches for their own use in studying problems in design, and for showing their clients the finished appearance of a proposed building. It is entirely unsuited for working drawings as it shows the object as it appears and not as it really is.

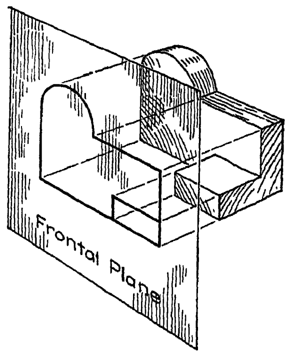


FIG. 202.—Orthographic projection.

95. If the observer will imagine himself as walking backward from the station point until he reaches a theoretically infinite distance, the rays formed by the lines of sight from his eye to the object will grow longer and finally become infinite in length, parallel to each other and perpendicular to the picture plane. The picture so formed on the picture plane is what is known as orthographic projection. If now all the rays from the picture plane to infinity be discarded, the picture can be thought of as being found by extending perpendiculars to the plane from all points of the object, Fig. 202. This picture, or projection on a frontal plane, will evidently have the same *width* and *height* as the object itself, but

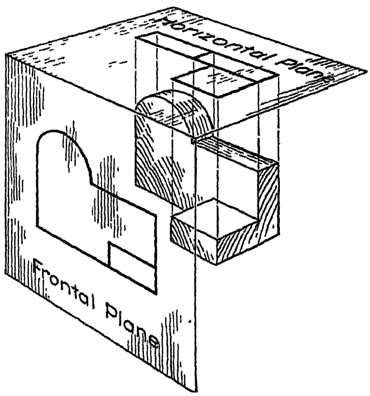


FIG. 203.—The planes of projection.

it will not tell the *depth* from front to back, hence more than one projection will be required to describe the object. In orthographic projection the picture planes are called *planes of projection* and the perpendiculars *projecting lines* or *projectors*.

If another transparent plane is imagined as placed horizontally above the object, as in Fig. 203, the projection on this plane, found by extending

perpendiculars to it from the object, will give the appearance of the object as if viewed from directly above, and will show exactly the width and depth. If this horizontal plane is now revolved into coincidence with the vertical

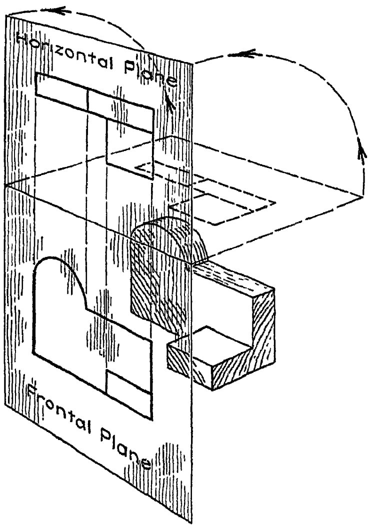


FIG. 204.—The horizontal plane revolved.

plane, as in Fig. 204, the two views of the object will then be in the same plane, as if on a sheet of paper; moreover, thus related in the same plane, they will correctly give the three-dimensional shape of the object. A third plane, called a profile plane, may be imagined, perpendicular to the first

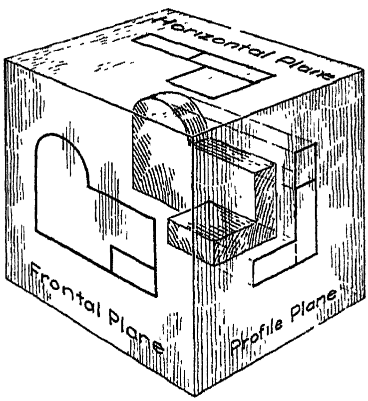


FIG. 205.—The profile plane.

two, Fig. 205, and on it a third view may be projected. The third view will show the true height of the object and the depth from front to back. The horizontal and profile planes are shown revolved into the same plane as the frontal plane (again thought of as the plane of the drawing paper) in Fig

206. The practical drawing procedures using this theory are described in the next chapter.

In looking at these theoretical projections, or views, the observer should not think of the views as being flat surfaces on the transparent planes but should imagine himself as looking *through* the transparent planes at the object itself.

96. Definition.—Theoretically, in a broad way, orthographic[1] projection could be defined as any single projection made by dropping perpendiculars to a plane. However, it has been accepted through long usage and common consent to mean the combination of two or more of such views, hence the following definition: **Orthographic projection** *is the method of representing the exact shape of an object in two or more views on planes generally at right angles to each other, by extending perpendiculars from the object to the planes.* (The term "orthogonal[2] projection" is sometimes used for this system of drawing.)

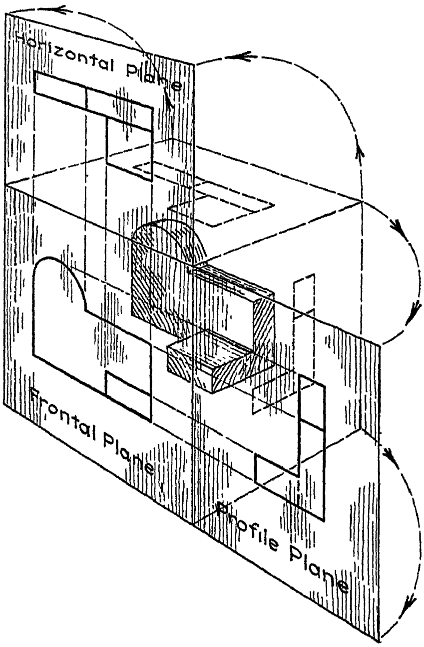


FIG. 206.—The profile plane revolved.

97. First-angle Projection.—The system of orthographic projection explained in this chapter is known as "third-angle projection." It is the official American Standard, universally adopted in the United States and Canada.

[1] Right-writing.
[2] Right-angled.

If the horizontal and vertical planes of projection should be extended beyond their intersection, four dihedral angles would be formed, which are called in order, "first," "second," "third" and "fourth angles," numbered as illustrated in Fig. 207. Theoretically, the object might be placed in any one of the four angles or quadrants, projected to the planes and the planes folded about their intersection. Practically, the second and fourth would be eliminated, leaving the first and third as possibilities. If the object is placed in the *first angle*, projected to the planes and the planes opened up into one plane, the top view would evidently fall below the front view, and if a profile plane were added the view of the left side of the figure would be to the right of the front view. This system of first-angle projection was formerly in universal use but was generally abandoned in this country some

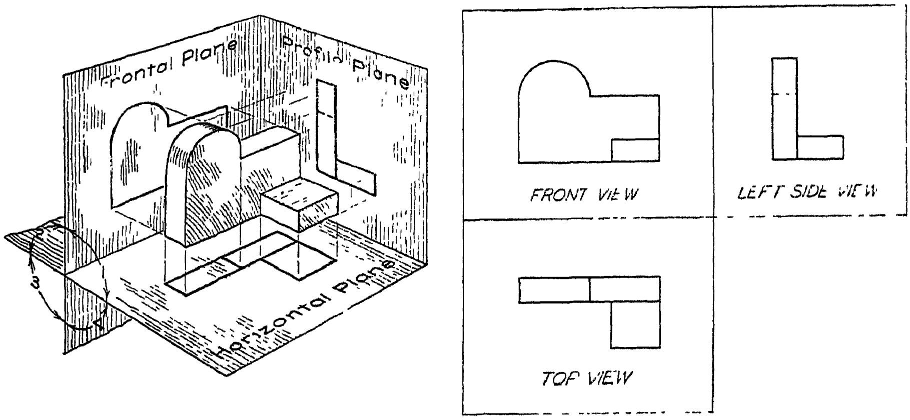


FIG. 207.—First-angle projection.

fifty years ago. The student should understand and recognize it, however, as it may be encountered occasionally in old drawings and illustrations as well as drawings from some foreign countries. Argument and confusion have arisen, and sometimes expensive mistakes have occurred, through the misreading of first-angle drawings as made by foreign-trained engineers.

98. One-plane Methods.—If, instead of being placed in its natural position parallel to the frontal plane of projection, the object is turned at an angle, then tilted forward, so that three of its faces can be seen, a special kind of "orthographic" projection known as *axonometric projection* will result. It has three subdivisions: isometric, dimetric and trimetric, all explained in Chap. XX.

Another division in the classification of methods of projection is that of oblique projection, in which the projectors, a system of parallel projecting lines, make an angle other than 90° with the plane.

Axonometric and oblique projection are classified, along with perspective, as one-plane pictorial methods; thus they are distinguished from the usual

PROJECTION DRAWING

- **Orthographic Projection**
  Projectors perpendicular to planes of projection
  - **Multiplanar**
    (Two or more planes)
    - **Two-view drawings**
    - **Three-view drawings**
    - **Drawings with auxiliary views.** *Page* 127
  - **Axonometric**
    (One plane)
    - **Isometric projection**
      Three axes making equal angles with plane *Page* 401
    - **Isometric drawing.** *Page* 401
    - **Dimetric projection**
      Two of the three axes making equal angles with plane. *Page* 408
    - **Trimetric projection**
      Three axes making unequal angles with plane. *Page* 408
- **Oblique Projection**
  Projectors oblique to planes of projection
  - (One plane)
    - **Cavalier projection**
      Two axes parallel to plane, projectors making an angle of 45° with it, in any direction. *Page* 408
    - **Cabinet projection**
      Two axes parallel to plane, projectors making an angle 63°25′ approximately, with it. *Page* 412
    - **Various oblique positions.** *Page* 409
    - **Clinographic projection** (obsolete)
      Object turned at an angle whose tangent is $\frac{1}{3}$. Projectors at an angle whose tangent is $\frac{1}{6}$. (Formerly used in crystallography)
- **Perspective Projection**
  Projectors converging to a fixed point
  - (One plane)
    - **Parallel perspective**
      Object with one face parallel to plane. *Page* 432
    - **Angular perspective**
      Two faces of object inclined to plane. *Page* 433
    - **Oblique perspective**
      Three faces of object inclined. (*Rarely used*)

orthographic projection, in which at least two planes are required to show the three dimensions of the object.

The different systems of projection are classified in tabular form on the preceding page, with page references to the text.

Map projection, covering the numerous and interesting methods of representing the curved surfaces of the earth on a plane, is not included in this table.

CHAPTER VII

ORTHOGRAPHIC PROJECTION

99. All material objects, from single pieces to complicated structures, have three dimensions in space. The problem in engineering drawing is to reproduce the exact shape of an object, with its three dimensions, on the surface of a sheet of paper, which has only two dimensions. To do this the system of orthographic projection, as explained in the previous chapter, has been devised. Practically, this means that the drawing is made up of

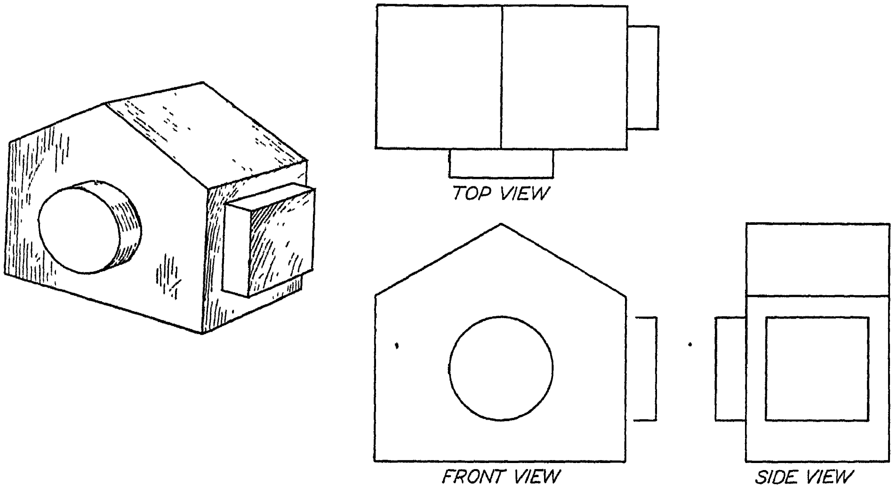


FIG. 208.—A block and its three views.

a set of separate views of the object taken by the observer from different positions and arranged relative to each other in a definite way. Each of these views will show two of the three dimensions, and thus a combination of two or more views will show the three dimensions of the piece. Illustrating with the block shown in Fig. 208, if the observer will imagine himself as in a position directly in front of the object (theoretically at an infinite distance, practically at a reasonable seeing distance but still assuming the rays from the points of the object to his eye as parallel), the *front view* would appear as marked. This view tells the width and the height but not the depth[1] of the block from front to back, nor what the circle represents.

[1] Several other combinations of words to designate the three directional dimensions, called here "width, height and depth" have been employed, such as "length, breadth and thickness," "length, width and height," "length, breadth and depth," etc. Those used

Then, without moving the block, let the observer change his position so as to look down from directly above it. He will now see the *top view*, giving the width and depth, and showing that the circle on the front view represents a short projecting cylinder, called in technical language a "boss."[1] It is necessary to have another view to show the shape of the extension on the right side of the piece, since this cannot be determined from the front and top views. A *right side view*, looking directly at the end of the piece, shows that the projecting part is square in shape. These three views arranged in their natural relative positions with the top view directly above the front view and the side view in line with the front view, completely describe the

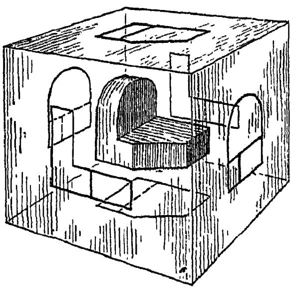


FIG. 209.—The transparent box.

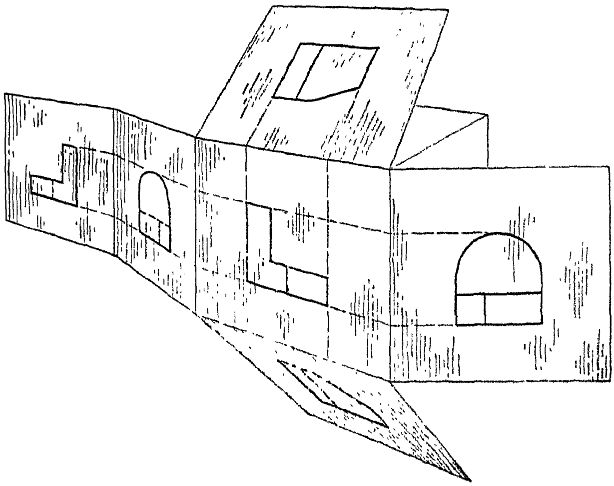


FIG. 210.—The box as it opens.

block. Note that *in the top and side views the front of the block always faces toward the front view.*

100. "The Glass Box."—Under the theory explained in Chap. VI, the object to be drawn may be thought of as surrounded by a box with transparent sides hinged to each other, through which the object can be seen, as in Fig. 209. The projections on these sides, made by extending perpendiculars from the object, are what would be seen by looking straight at the object from positions directly in front, above and from both sides, as well as from the bottom and rear. These planes are then to be thought of as being opened up, as illustrated in Fig. 210, into one plane, the plane of the paper. The projection on the front plane is known as the *front view,*

here have become standard in direct method descriptive geometry. The word "depth" is used in the civil engineering sense, as the depth of a lot. It should be noted that these terms refer to the three fixed directions and are not at all dependent on the shape or position of the object represented.

[1] See Glossary.

vertical projection, or *front elevation;* that on the horizontal plane the *top view, horizontal projection*, or *plan;* that on the side or "profile" plane the *side view, profile projection, side elevation* or sometimes *end view* or *end elevation.* In comparatively rare cases either a *bottom view* or a *rear view*

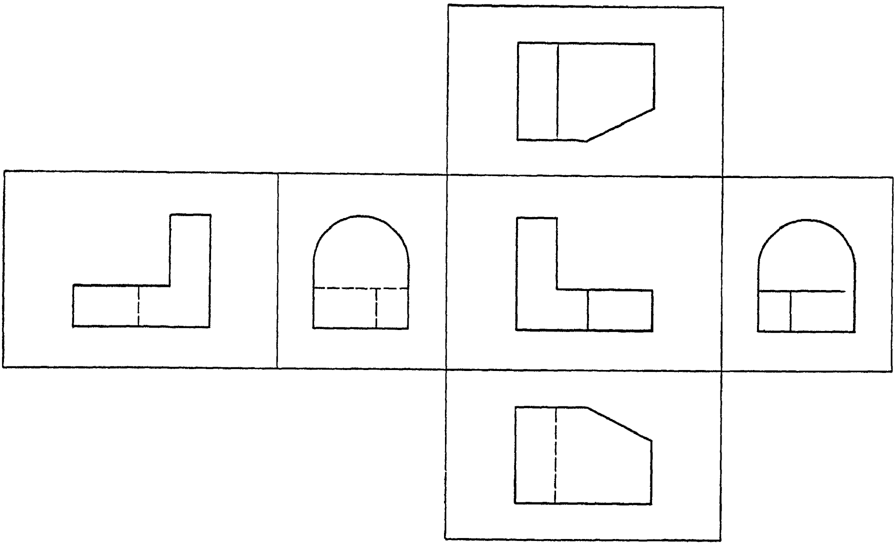


FIG. 211.—Relative positions of the six views.

or both may be required to show some detail of shape or construction. Figure 211 shows the relative positions of the six views as set by the American Standards Association. In actual work there is rarely ever an occasion where all six principal views would be needed on one drawing, but, no matter how many are required, their positions relative to each other would

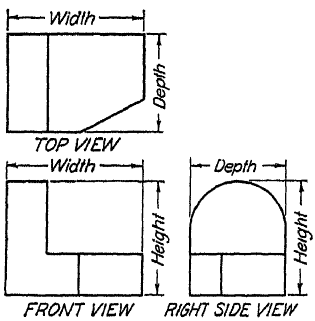


FIG. 212.—Three projections.

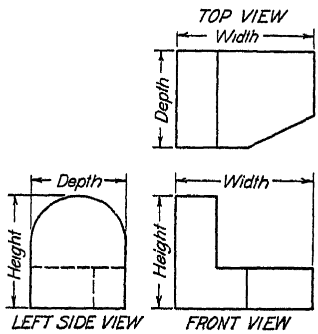


FIG. 213.—Three projections.

be as given in Fig. 211. The most usual combination is *top, front* and *right side* views as shown in Fig. 212, selected from the six possible views, and which in this case best describe the shape of the given block. Sometimes the left side view will help describe an object more clearly than the right side would. Figure 213 shows the arrangement of *top, front* and *left side*

views (in this case the right side view would be preferred as it has no hidden lines). Note again that the *side view of the front face of the object is adjacent to the front view,* and that the side view of any point will be the same distance horizontally from the front edge as is its distance from the front edge on the top view. The combination of *front, right side* and *bottom views*

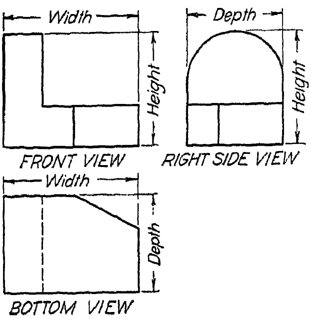


Fig. 214.—Three projections.

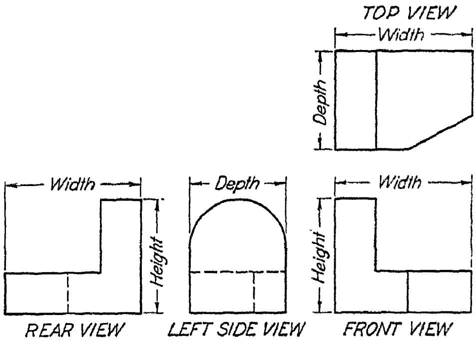


Fig. 215.—Position of rear view.

is shown in Fig. 214 and that of *front, top, left side* and *rear* views in Fig. 215.

101. Second Position.—The ends of the glass box may be conceived as hinged to the top instead of the front plane, as illustrated in Fig. 216, thus bringing the side views in line with the top view, Fig. 217. This second-position arrangement is of occasional use in drawing a broad, flat object, as

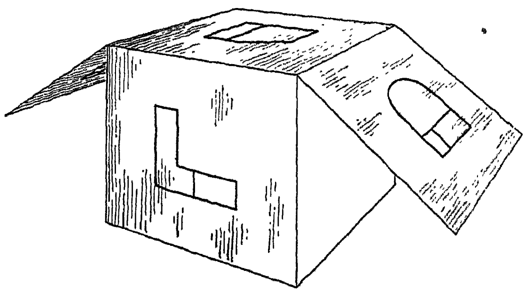


Fig. 216.—Side views (second position).

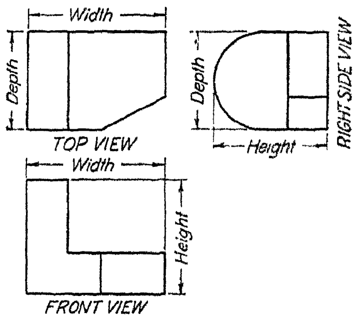


Fig. 217.—Side view in second position.

it saves space on the paper. It is extensively used in three-view drawings of aircraft.

102. Numbering Corners.—In comparing projections with the object or its picture it will be of much help to the beginner to letter (or number) the corners of the object, and, with these identifying marks, to letter similarly the corresponding points on each of the views, as in Fig. 218. Hidden points directly behind visible points are lettered to the right of the letter of the visible point, and in this figure they have been further differentiated

by the use of a dotted or "phantom" letter. Study Fig. 219 by numbering the corners of the three views to correspond to those of the pictorial view.

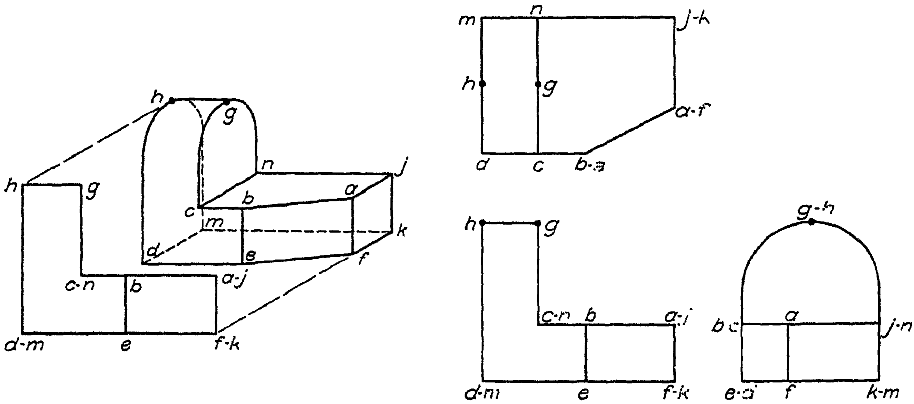


FIG. 218.—Identified corners.

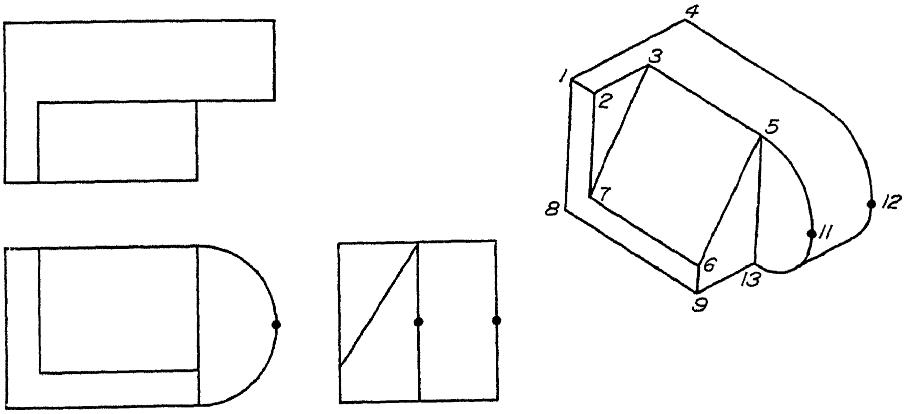


FIG. 219.—Projection study.

103. Principles.—From the foregoing study the following principles will be noted:

1. The top view is directly over the front view.
2. The side views are in line horizontally either with the front view or the top view.
3. The depths of the side view are exactly the same as the depth (measurement from front to back) of the top view.
4. A surface parallel to a plane of projection is shown in its true size.
5. A surface perpendicular to a plane of projection is projected on that plane as a line.
6. A surface inclined to a plane of projection is shown foreshortened on that plane.

Similarly,

7. A line parallel to a plane of projection will show in its true length on that plane.
8. A line perpendicular to a plane of projection will be projected on that plane as a point.
9. A line inclined to a plane will have a projection on that plane shorter than its true length.

104. Hidden Lines.—To describe an object completely a drawing should contain lines representing all the edges, intersections and contours of the object. *In any view there will be some parts of the object that cannot be seen from the position of the observer as they will be covered by portions of the object closer to the observer's eye.* The edges, intersections and contours of these hidden parts, although actually invisible, have their location indicated

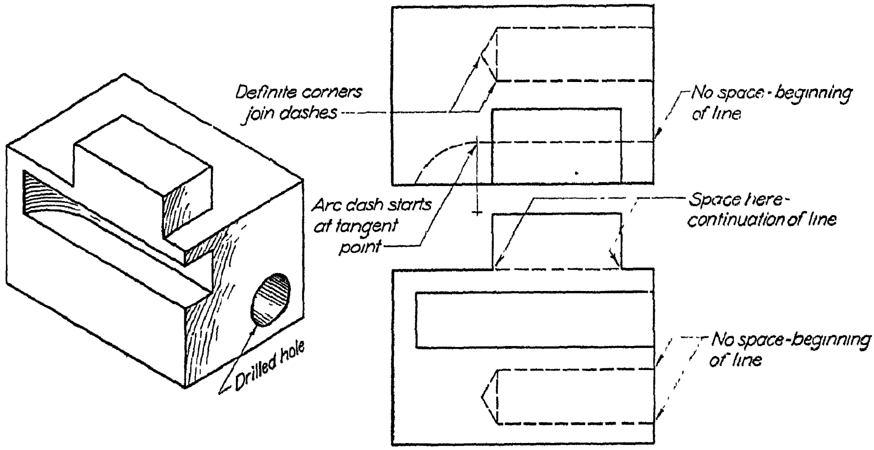


FIG. 220.—Hidden lines.

by the symbol of a line made up of short dashes, sometimes called by draftsmen "dotted lines." In Fig. 220 the drilled hole[1] which would be visible in the right side view is invisible in the top and front views, and so it is indicated by a hidden line showing the depth of the hole and the shape of the bottom as left by the drill point. The milled slot[1] is visible in the front and side views but is invisible in the top view.

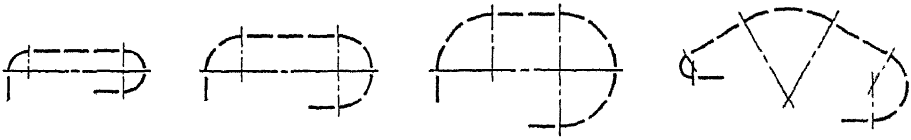


FIG. 221.—Hidden arcs.

The beginner must pay particular attention to the execution of these hidden lines. If carelessly drawn they will not only ruin the appearance of a drawing but will make it much harder to read. The line is drawn lighter than the full lines, of short dashes uniform in length, with the space between them very short, less than half the length of the dash. It is important that they start and stop correctly. A hidden line always starts with a dash except when it would form a continuation of a full line, in which case a space

[1] See Glossary.

is left, as shown in Fig. 220. Dashes always meet at corners. An arc must start with a dash at the tangent point, except when it would form a continuation of a full line, straight or curved, thus, according to size, a quarter-round might be made of one dash, two dashes etc. See Fig. 221. In any view a hidden line directly behind a full line would not be indicated. Study carefully all hidden lines in Figs. 220 and 222.

105. Center Lines.—In general the first lines to be drawn in the layout of an engineering drawing are the center lines, forming the axes of symmetry for all symmetrical views. (1) Every part with an axis, as a cylinder or a cone, will have the axis drawn as a center line before the part is drawn. (2) Every circle will have its center at the intersection of two center lines. Center lines must cross without voids.

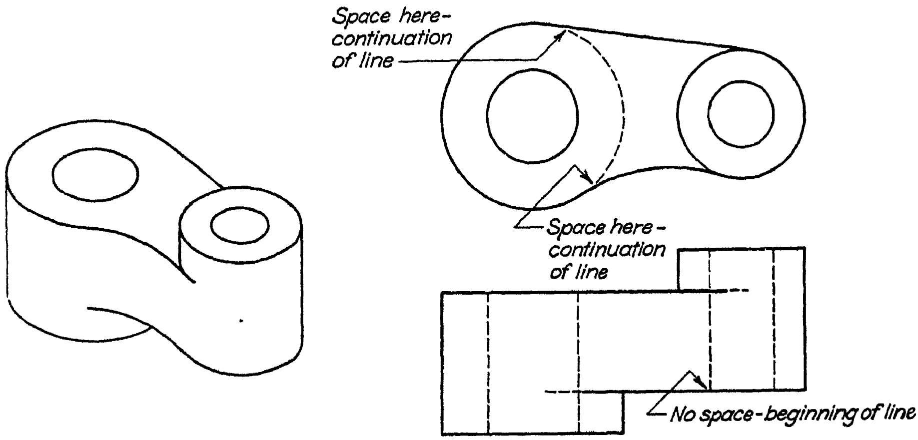


FIG. 222.—Hidden lines.

The standard symbol for center lines is a fine line made up of alternate long and short dashes, as shown in the alphabet of lines, Fig. 46. They are always extended slightly beyond the outline of the figure. Center lines form the skeleton construction of the drawing, from and to which the important measurements are made and dimensions given Study the center lines in Figs. 223, 224 and 228.

106. Precedence of Lines.—In any view there is likely to be a coincidence of lines. A surface perpendicular to a plane of projection is shown on that plane as a line. This may be considered as the nearest edge of the surface and any other lines on the surface consequently could not be seen. Thus the principle that *when two lines coincide the nearer one has precedence.* A visible line could cover up a hidden line but a hidden line could not cover a visible line. Evidently a dashed line could not occur as a part of the boundary line of a view. When a center line or cutting plane coincides with a hidden line the hidden line has precedence. A cutting plane may have

precedence over a center line. A full line has precedence over any other kind of a line. Find the coincident lines in Fig. 223.

107. Selection of Views.—In practical work it is very important to choose the combination of views that will describe the shape of an object in the best and most economical way. Often only two views are necessary, as for example, a cylindrical shape, which if on a vertical axis, would require only a front and a top view and if on a horizontal axis, only a front and a side view. Conical and pyramidal shapes also may be described in two views. Figure 224 illustrates two-view drawings. On the other hand some shapes will need more than the three regular views for adequate description.

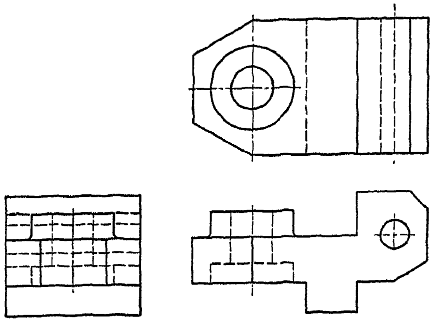


FIG. 223.—Coincident-line study.

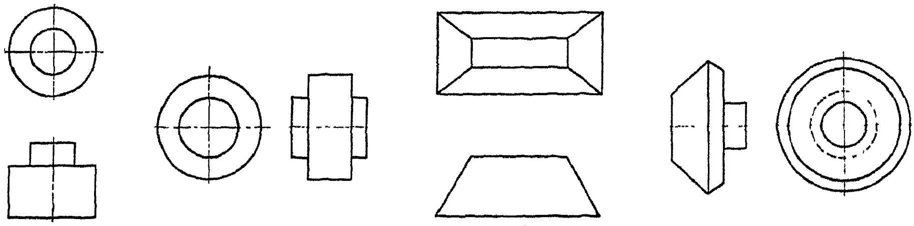


FIG. 224.—Two-view drawings.

Objects may be thought of as being made up of combinations of simple geometrical solids, principally cylinders and rectangular prisms, and the views necessary to describe any object would be determined by the directions from which it would have to be viewed to see the characteristic contour shapes of these parts. Figure 225, for example, is made up of several prisms and cylinders. If each of these simple shapes is described and their relation to each other is shown, the object will be fully represented. In the majority of cases the three regular views, top, front and side, are sufficient to do this.

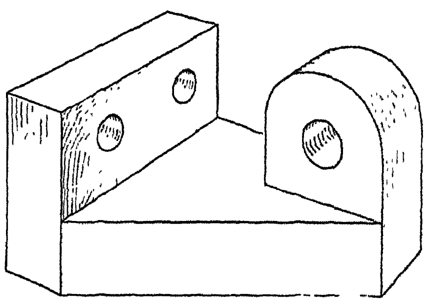


FIG. 225.—Geometric shapes combined.

Sometimes two views are proposed as sufficient for some object on the assumption that the contour in the third direction would be of the shape that would naturally be expected, as *A*, Fig. 226, which would be assumed to have a uniform cross section and be a square prism. But the two views

might be the top and front views of a wedge, as shown in three views at *B*. Two views of an object as drawn at *C* do not describe the piece at all. It might be assumed to be square in section, but it could as easily be round,

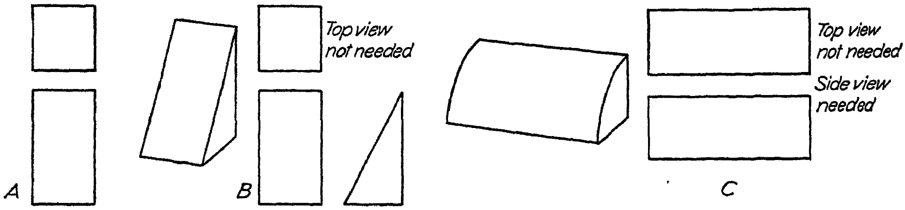


FIG. 226.—A study of views.

triangular, quarter-round, or other shape, which should have been indicated by a required side view. Sketch several different front views for each top view (*A*, *B* and *C*), Fig. 227.

The *front view* is usually the principal view. With the object in its functioning position select for the front view the direction showing the largest dimension and preferably the characteristic contour or shape of the piece. Visualize the object, mentally picturing the orthographic views one at a time to decide on the best combination. In Figure 228 the arrows show the direction of observation for the six principal views of an object and

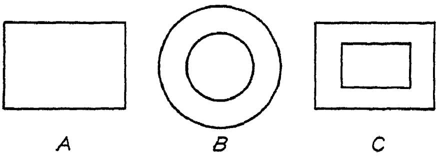


FIG. 227.—Top views given.

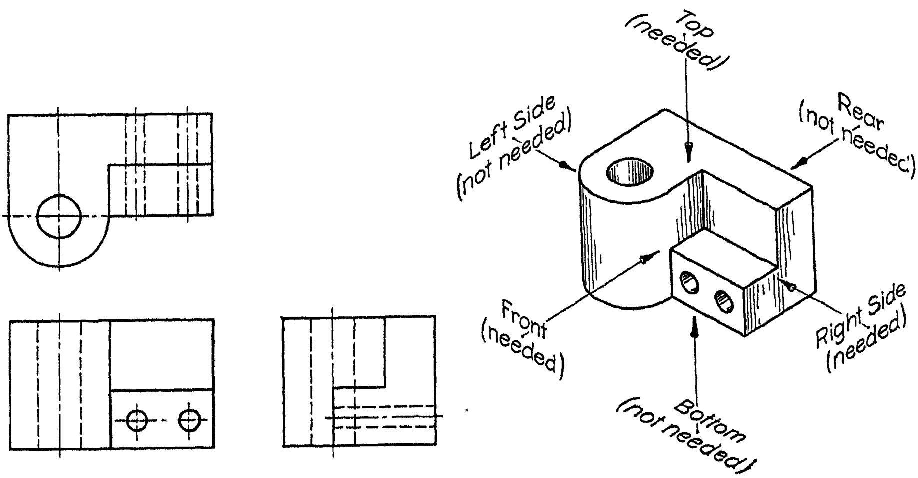


FIG. 228.—Selection of views.

indicate the mental process of the draftsman. He notes that the front view should show the two horizontal holes, as well as the width and height of the piece; that a top view is needed to show the contour of the vertical cylinder, and that the cut out corner will require a side view to show its shape. He

notes further that the right side view would show this cut in full lines while on the left side it would be invisible. He notes incidentally that neither a bottom view nor a rear view would be of any value in describing this object (in practical work not once in a hundred drawings would these views be used). Thus he has arrived at the correct choice of front, top and right side views for the best description of the piece. As a rule the side view containing the fewer hidden lines should be preferred. If there is no choice the right side view has the preference in standard practice.

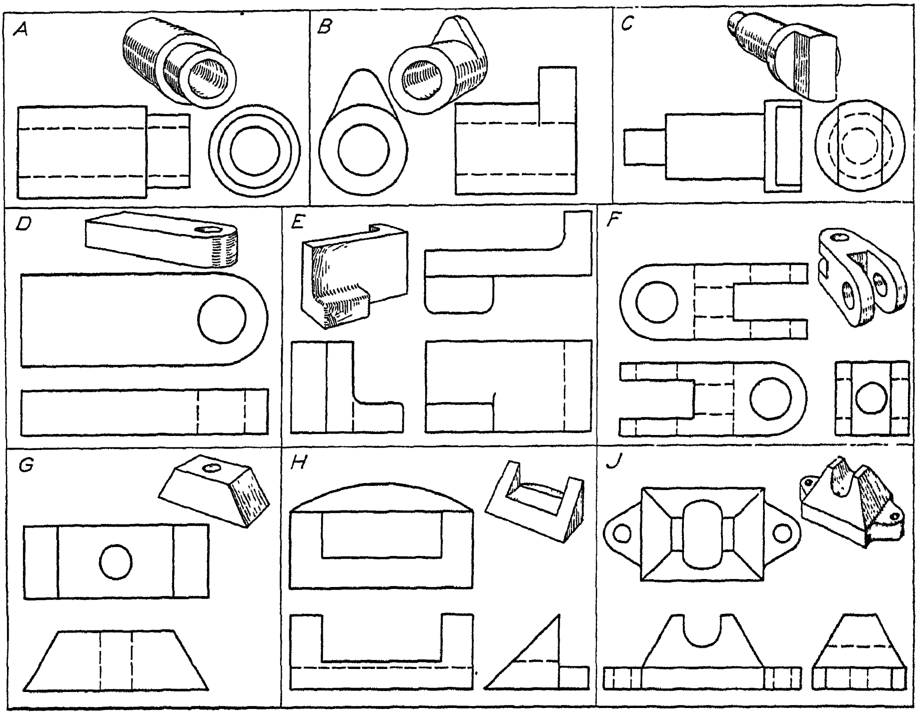


FIG. 229.—Projection studies.

In inventive and design work any simple object would be visualized mentally and the views selected without a picture sketch. In complicated work a pictorial or orthographic sketch may be used to advantage, but it would not be necessary in any case to sketch all possible views in order to make a selection.

Study the drawings in Fig. 229 and determine why the views are so chosen.

108. Sketching in Orthographic Projection.—In beginning the study of projections it is best to draw freehand the three views of a number of simple pieces, developing the ability to "write" the language and exercising the constructive imagination in seeing the object itself by looking at the three projections. Figures 230 and 231 contain a number of pictorial

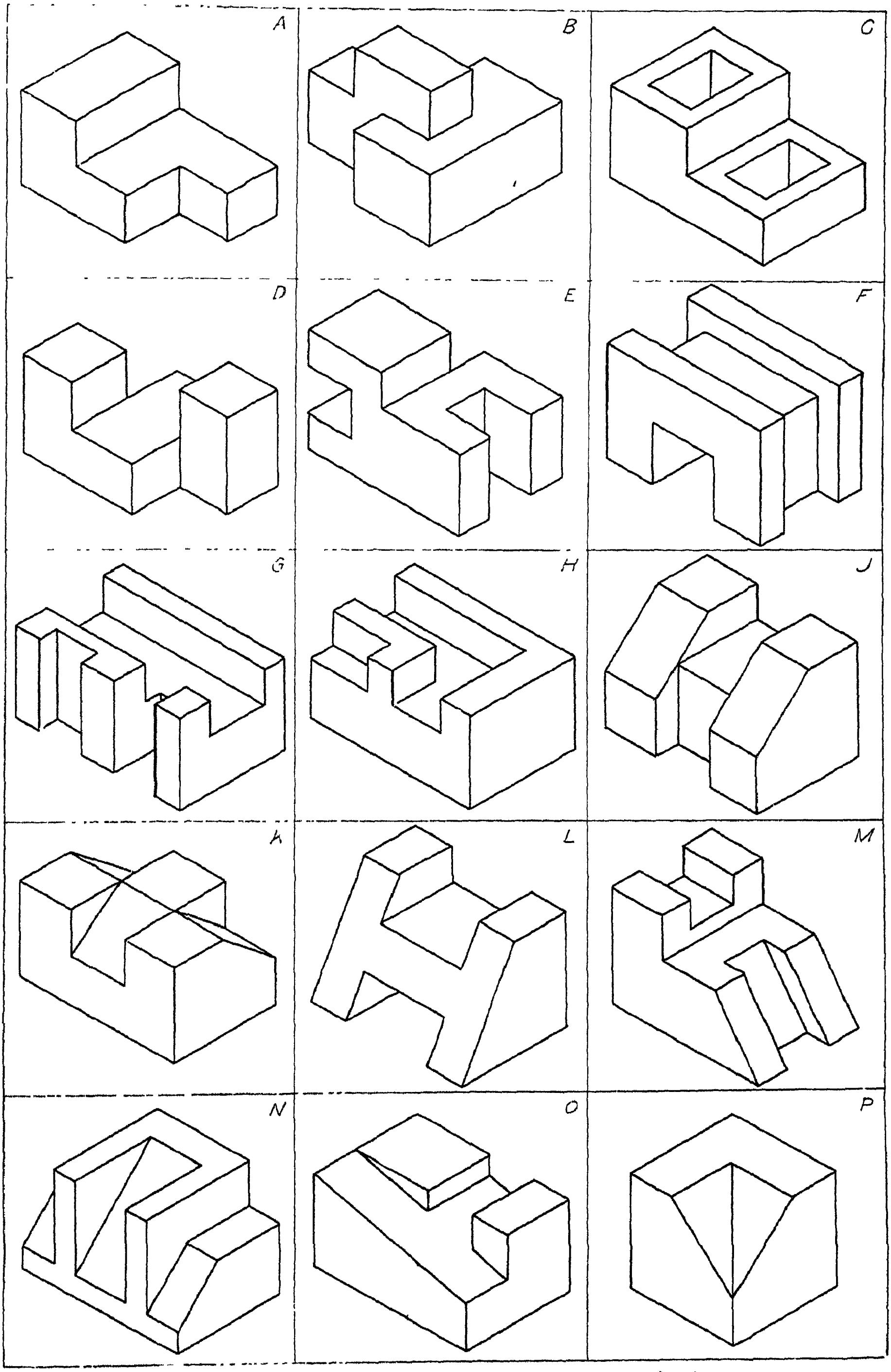


FIG. 230.—Pieces to be sketched in orthographic projection.

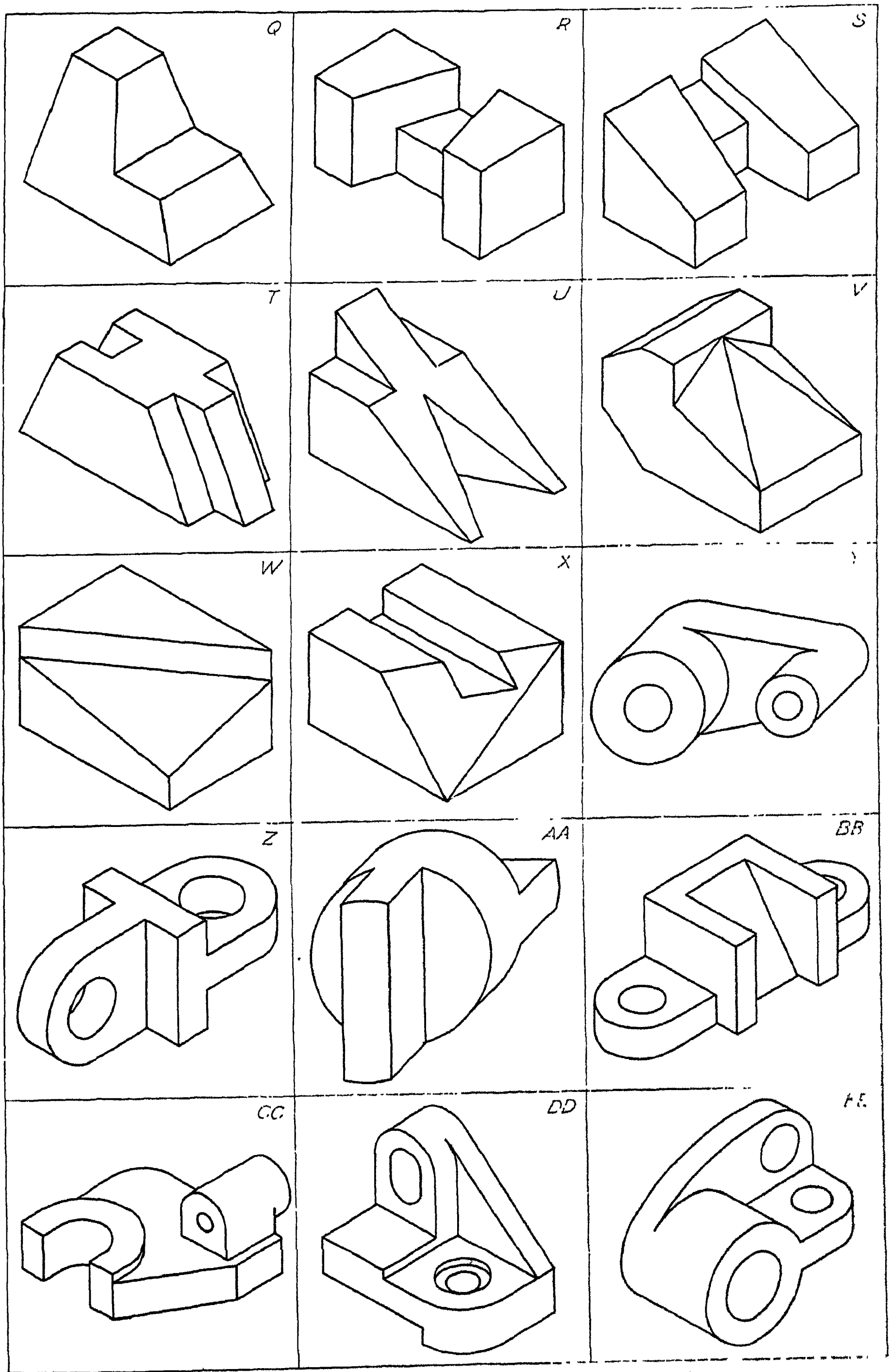


FIG. 231.—Pieces to be sketched in orthographic projection

sketches of pieces of various shapes. These are to be translated into three-view orthographic sketches. Make them of fairly large size, the front view say one and one-half to two inches in length, and estimate the proportions of the different parts by eye, without measuring. Observe the following order of working:

1. Study the pictorial sketch and decide what combination of views will best describe the shape of the piece.
2. Block in the views, as at *A*, Fig. 232, using a very light stroke of a soft pencil (F or No. 2), spacing the views so as to give a well-balanced appearance to the sketch.

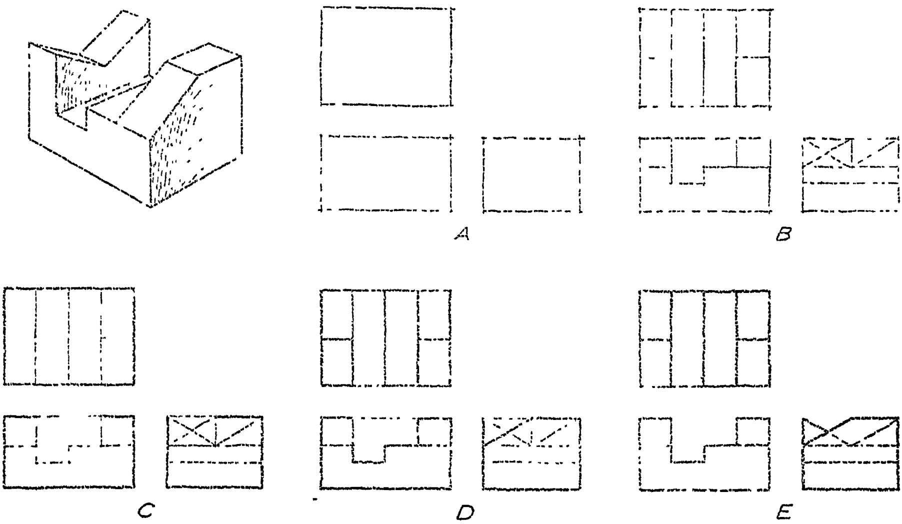


Fig. 232.—Stages in making an orthographic sketch.

3. Build up the detail in each view, carrying the three views along together, as at *B*.
4. Brighten the outline of each view with bold strokes as at *C*.
5. Brighten the detail with bold strokes, thus completing the full lines of the sketch, as at *D*.
6. Sketch in all hidden lines, using a stroke of medium weight, lighter than the full lines, as at *E*, thus completing the shape description of the block.
7. Check the sketch carefully, then cover the pictorial sketch and visualize the object from the three views.

In making three-view sketches from measured models or dimensioned pictorial drawings, as Figs. 245, etc., faintly ruled quadrille paper is sometimes used to advantage.

It will be of interest to read Chap. XVIII on technical sketching before working the problems of Figs. 230 and 231.

109. Reading a Drawing.—As already stated, the engineer must be able to *read* and *write* the language of drawing. In the previous paragraph some practice in writing has been given in the translation of pictorial sketches into orthographic views. The necessity of learning to *read* is, if possible, of even more importance, as everyone connected with

technical industry must be able to read a drawing without hesitation. Not to have that ability would be an admission of technical illiteracy.

A drawing cannot be read aloud but is interpreted by forming a mental image of the object represented. This mental image may be reproduced by making the piece in wood or metal, by modeling it in clay, or by making a pictorial sketch of it, the latter being the more usual method.

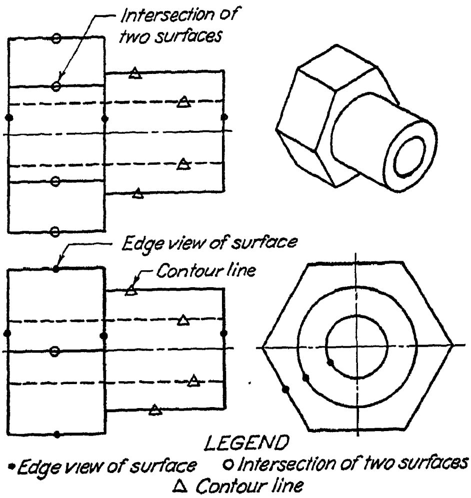


FIG. 233.—What a line indicates.

A line on a drawing always indicates either the edge view of a receding surface, the intersection of two surfaces, or a contour. Figure 233 illustrates this distinction. One cannot read a drawing by looking at one view. Each line on a view means a change in the direction of a surface, but the corresponding part of another view must be consulted to tell what the change is. For example, a circle on a front view, as in Fig. 208, may mean either a hole or a projecting boss. A glance at the side view or top view will tell at once which it is.

In reading a drawing one should first gain a general idea of the shape of the object by a rapid survey of all the views given, then select for more careful study the view that best shows the characteristic shape, and by referring back and forth to the adjacent views see what each line represents.

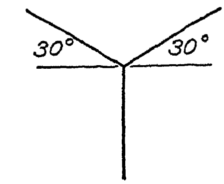


FIG. 234.

In looking at any view one should always imagine that it is the object itself, not a flat projection of it, that is seen, and in glancing from one view to another the reader should imagine himself as moving around the actual object and looking at it from the direction the view was taken.

110. Reading by Sketching.—One of the best ways of reading a drawing is to start a pictorial sketch of the object. Usually before the sketch is finished the orthographic drawing will be perfectly clear. Since facility in freehand sketching is so important to every engineer its practice should be commenced early. Practice in orthographic sketching has already been proposed in paragraph 108. Practice in pictorial sketching requires a little preliminary study of the method of procedure.

Pictorial Sketching is based on a skeleton of three axes, one vertical, the other two at 30 degrees,[1] representing three mutually perpendicular lines, Fig. 234. On these axes are marked the proportionate width, depth and

[1] Isometric position.

height of any rectangular figure. Circles are drawn in their circumscribing squares.

In Fig. 235 look at the views given, as described in paragraph 109, then with a soft pencil (F) and notebook paper make a *very light* pictorial construction sketch, estimating the height, width and depth of the object and laying the distances off on the axes as at *A*; then sketch the rectangular box that would enclose the piece, or the block from which it could be cut, Fig. 235*B*. On the top face of this box sketch very lightly the lines that occur on the top view of the orthographic drawing, Fig. 235*C* (note that, as will be found later, some of the lines on top views may not be in the top plane). Next sketch lightly the lines of the front view on the front face of the box, or block and, if a side view is given, outline it similarly, Fig. 235*D*. Now

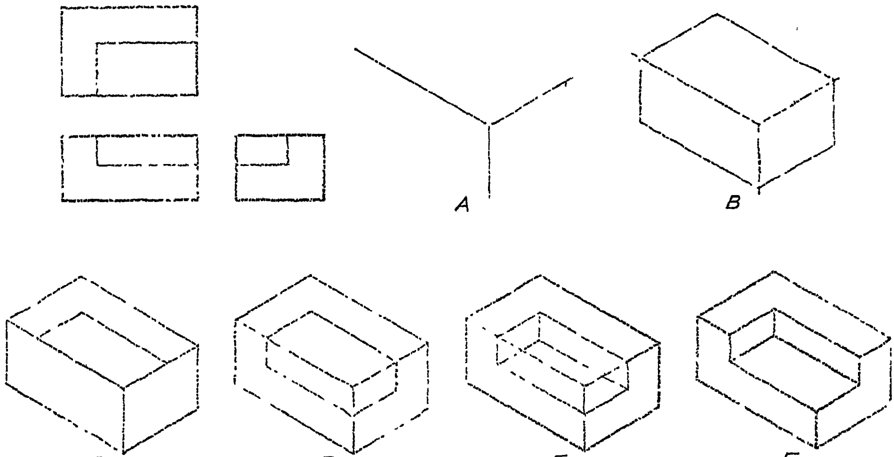


FIG. 235.—Stages in making a pictorial sketch.

begin to cut the figure from the block, strengthening the visible edges, and adding the lines of intersection where faces of the object meet, as in Fig. 235*E*. Edges that do not appear as visible lines are omitted unless necessary to describe the piece. Finish the sketch, checking back to the three-view drawing. The construction lines need not be erased unless they confuse the sketch.

A drawing as simple as the one in Fig. 235 can be read and the mental picture formed at a glance, so a sketch may be made very quickly; one with more lines will require a little more time for study, comparison of the different views and completion of the sketch. *One cannot expect to read a whole drawing at once any more than he would expect to read a whole page of print at a glance. Both must be read a line at a time.*

111. Reading by Modeling.—An interesting and effective way to read a drawing is to model the object in clay or modeling wax, working in much the same way as when reading by pictorial sketching. Some shapes may be

modeled by cutting out from the enclosing block, others may be modeled more easily by building up out of the geometric shapes into which the object may be analyzed and divided.

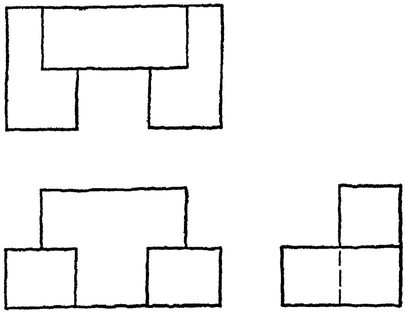


FIG. 236.

Starting with a rectangular block of clay, perhaps one inch square and two inches long, read Fig. 236 by cutting the figure from the solid. Scribe very lightly with the point of the knife or a scriber, the lines of the three views on the three corresponding faces of the block, Fig. 237*A*. Evidently the first cut could be as shown at *B*, and the second as at *C*. Successive cuts are indicated at *D* and *E* and the finished model at *F*.

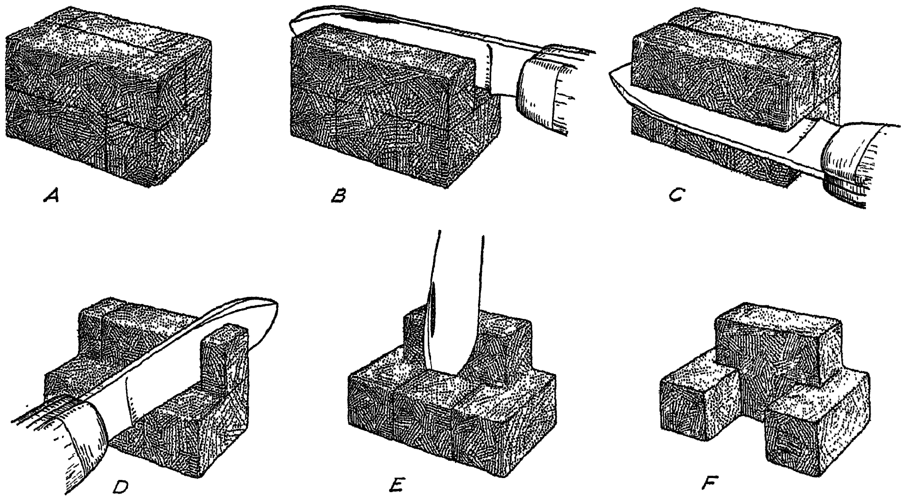


FIG. 237.—Stages in modeling.

Figure 238 illustrates the type of model that can be made by building up the shapes of which the object is composed.

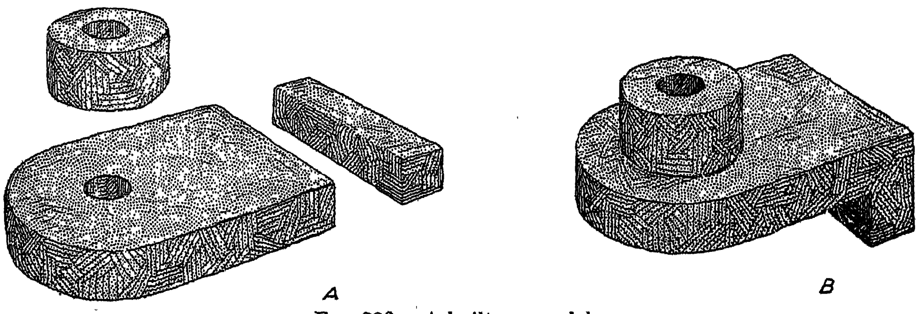


FIG. 238.—A built-up model.

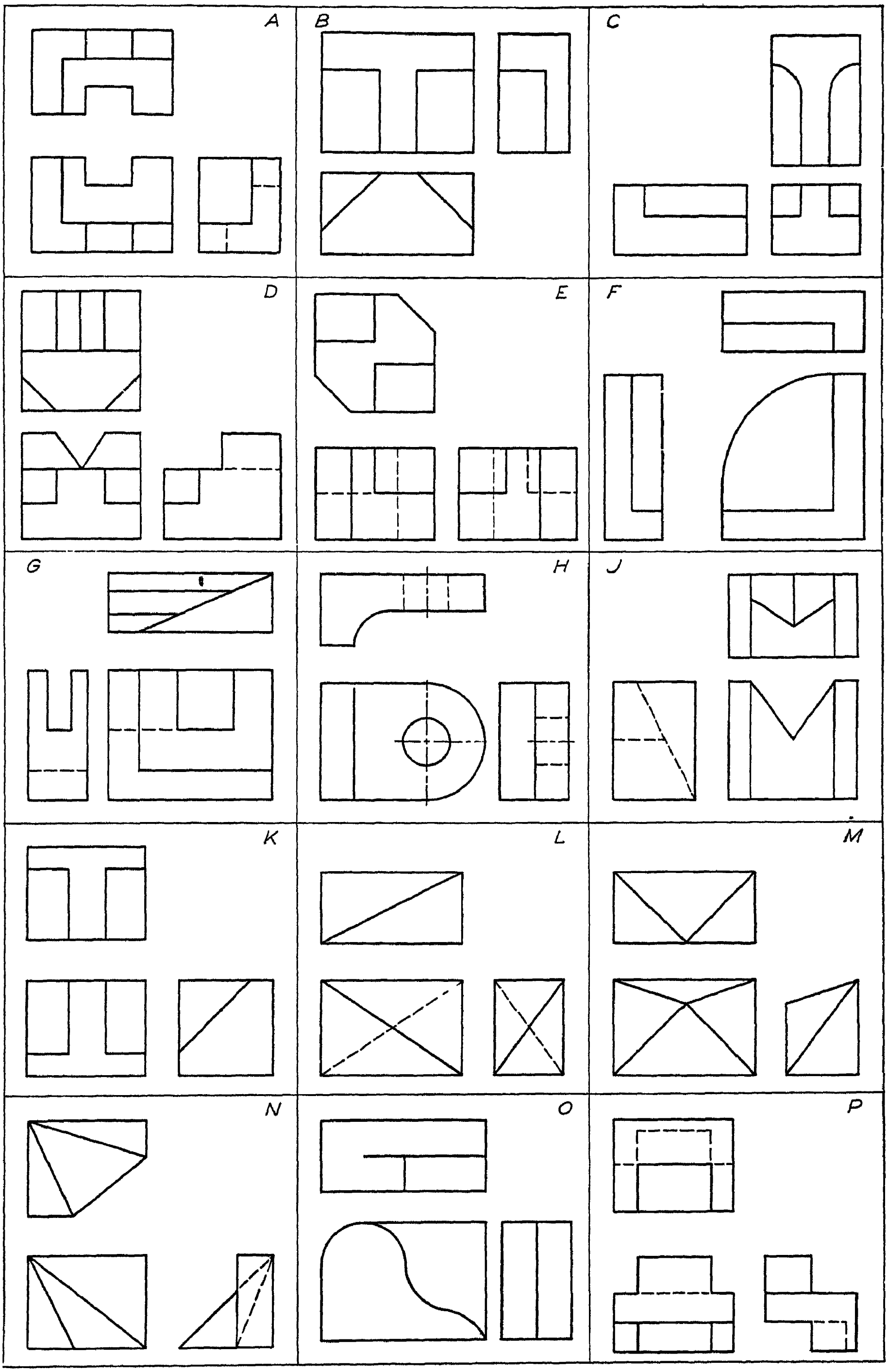


FIG. 239.—Reading exercises.

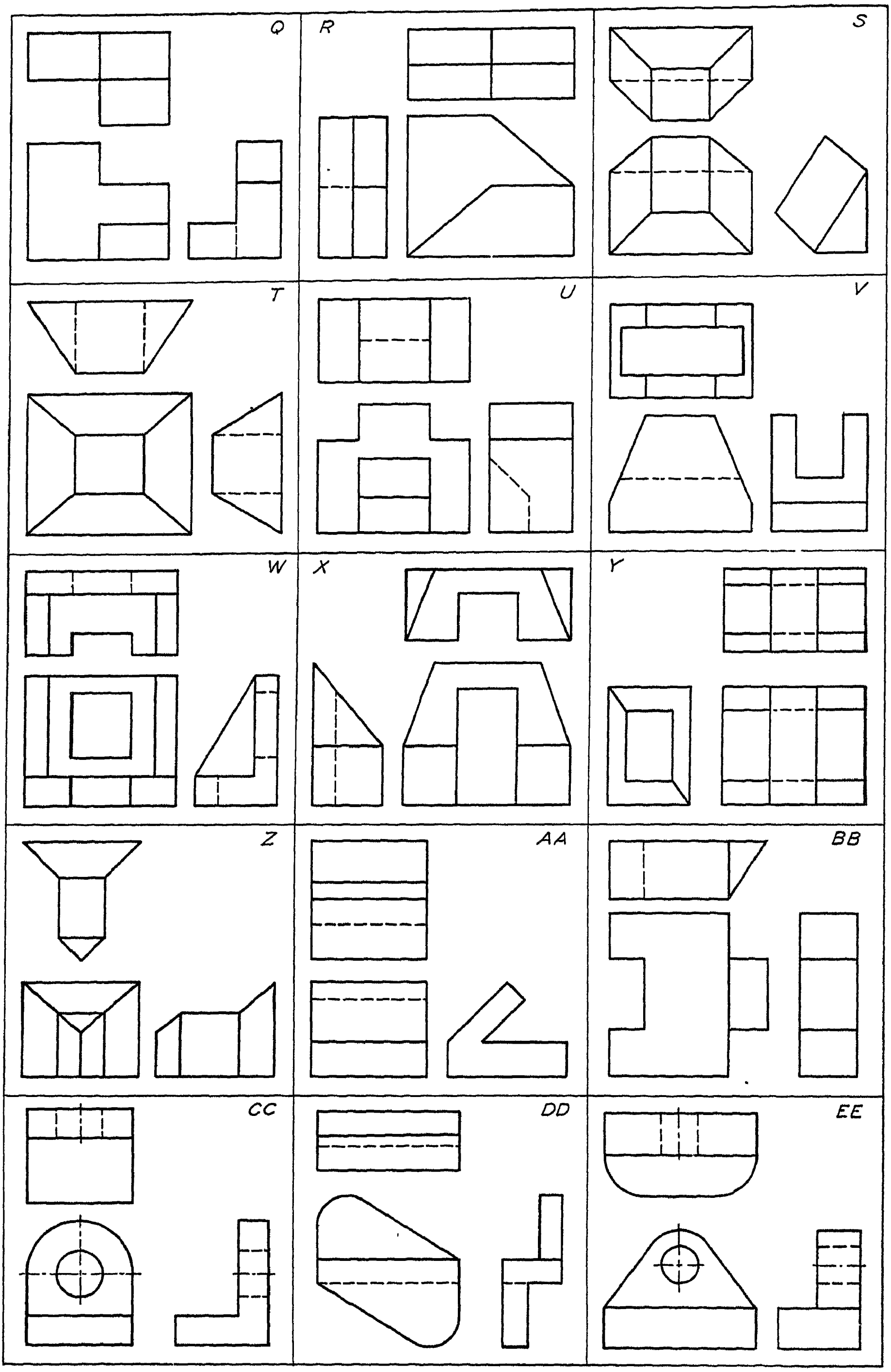


FIG. 240.—Reading exercises.

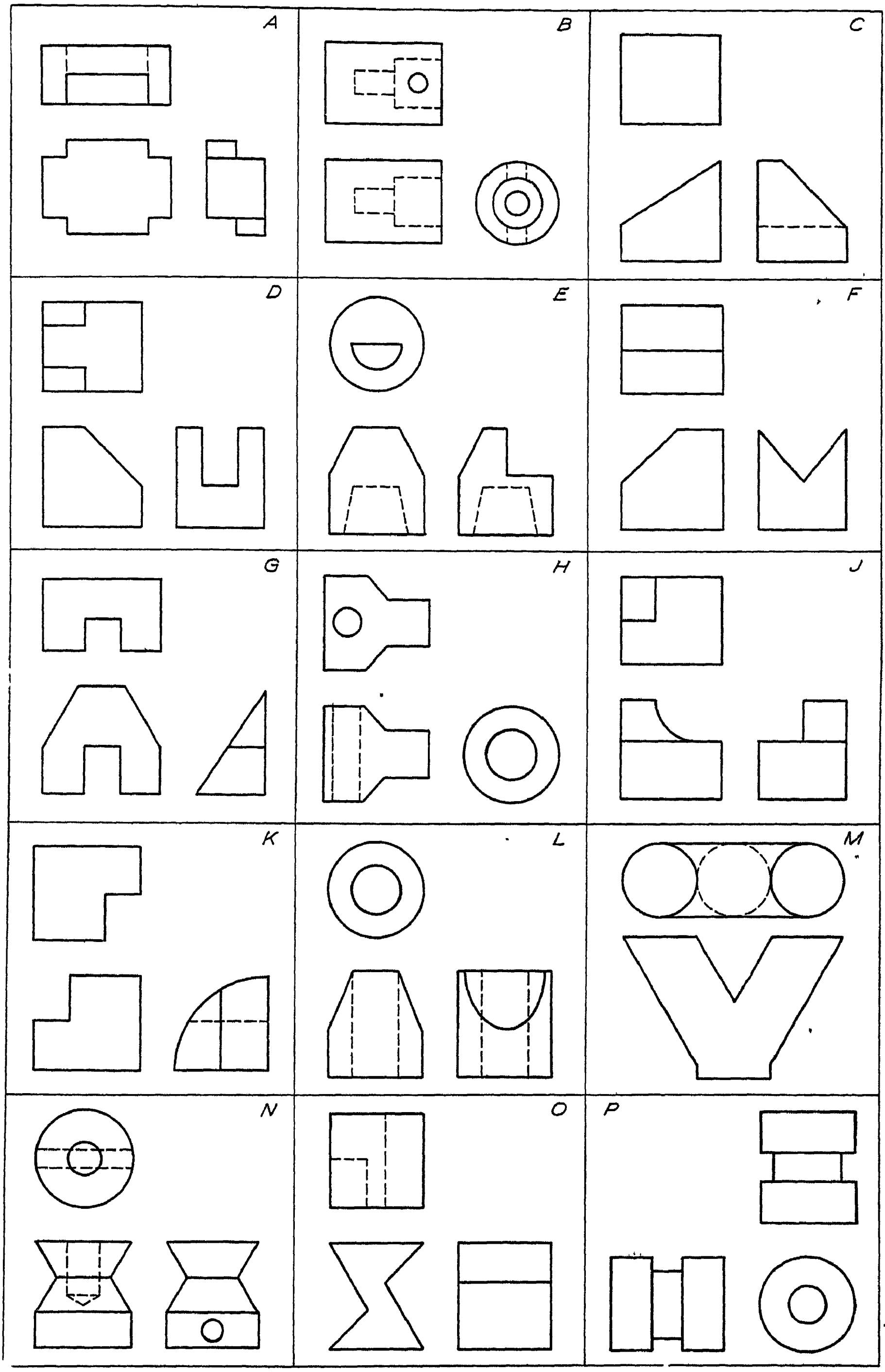


FIG. 241.—Missing-line exercises.

112. Exercises in Reading.—Figures 239 and 240 contain a number of three-view drawings of block shapes made for exrecises in reading orthographic projection and translating into pictorial sketches or models. Proceed as described in the previous paragraphs, making sketches not less than four inches over-all. Check each sketch to be, sure all intersections are shown and that the original three-view drawing could be made from the sketch.

In each three-view drawing of Fig. 241 some lines have been intentionally omitted. Read the drawings and supply the missing lines.

113. Spacing Views.—Drawings are made on standard sizes of sheets. The American Standard is based on multiples of $8\frac{1}{2}'' \times 11''$, thus,

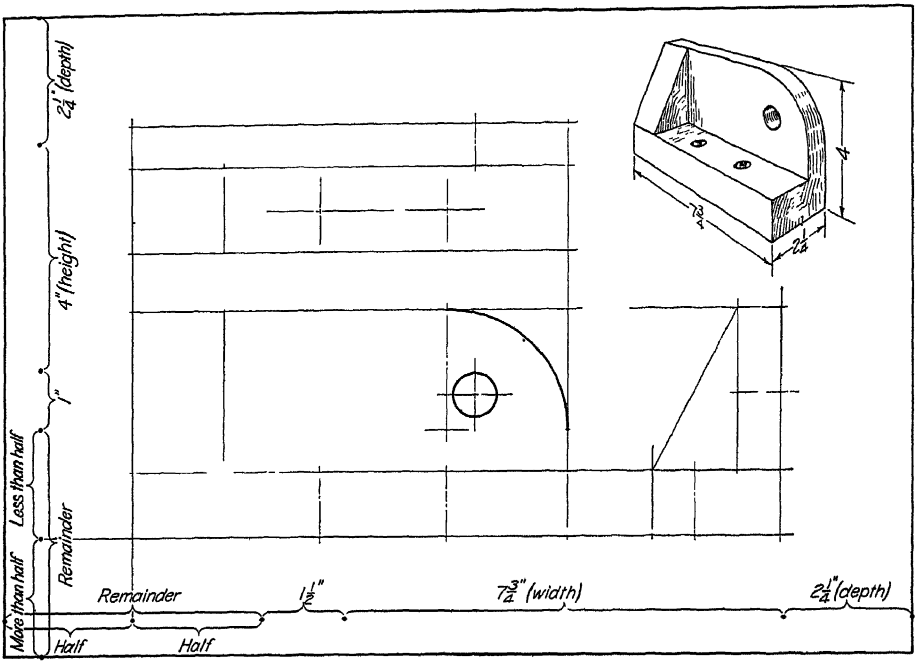
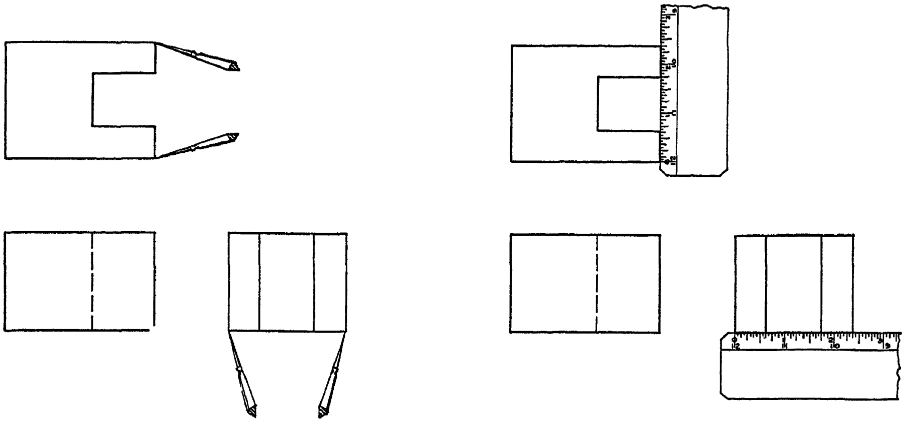


FIG. 242.—Spacing views.

$11'' \times 17''$, $17'' \times 22''$, etc. Views must be placed so as to fit the space provided, therefore the draftsman must do a little preliminary measuring before laying out his center and base lines for the different views. The following example will describe the procedure. Suppose the piece illustrated in Fig. 242 is to be drawn on an $11'' \times 17''$ sheet. With an end title strip the working space inside the border will be $10\frac{1}{2}'' \times 15\frac{1}{8}''$. The front view will require $7\frac{3}{4}''$ and the side view $2\frac{1}{4}''$. This leaves $5\frac{1}{8}''$ to be distributed between the views and at the ends.

The draftsman locates the views graphically, and very quickly, by measuring with his scale along the bottom border line. Starting at the lower *right* corner lay off first $2\frac{1}{4}''$, then $7\frac{3}{4}''$; the distance between views may

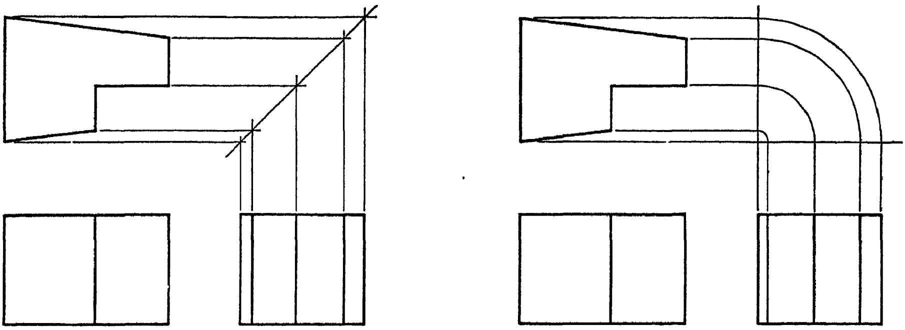
now be decided upon, (generally about one-third of the total distance remaining, in this case $1\frac{1}{2}''$) and the distance measured; half the remaining distance to the left corner is the starting point of the front view. For the vertical location, the front view is $4''$ high and the top view $2\frac{1}{4}''$ deep. Starting at the upper left corner, lay off first $2\frac{1}{4}''$, then $4''$; judge the



A B

FIG. 243.—Transferring measurements.

distance between views (in this case $1''$) and lay it off; then a point marked at less than half the remaining space will locate the front view and allow more space at the bottom than at the top, for appearance's sake. Now block out the views and locate center lines and base lines as shown. In carrying the top and side views along together the draftsman usually transfers the



A B

FIG. 244.—Projecting depth measurements.

depth measurements from one to the other either with his dividers, as at *A*, Fig. 243, or with his scale as at *B*, but sometimes, as in the case of an irregular figure, he finds it easier to "miter" the points around, using a 45-degree line drawn through the point of intersection of the lines of the top and side views of the front face, extended as shown in Fig. 244*A*; or,

going back to the method of the glass box, to swing them around with the compasses, as at *B*.

PROBLEMS

114. Selections from several groups of problems following are to be made for practice in projection drawing. Most of them are intended to be drawn with instruments but will give valuable training done freehand on either plain or coordinate paper.

The groups are as follows:

I. Projections from pictorial views.
II. Views to be supplied.
III. Views to be changed.
IV. Drawing from memory.
V. Volume and weight calculations (with slide rule).

The two things to be told about an object are its *shape* and its *size*. The former is given by the projections, the latter, which is just as important, is given by dimensions. These problems, although designed primarily for shape description, may be drawn as introductory working drawings by adding dimension lines and figures. If this is done, Chap. XI on dimensioning must be studied carefully, and the dimensions placed according to the rules given and checked for accuracy.

The first requirement of a good drawing, after the requisite views have been determined, is that the views be well spaced on the sheet and in relation to each other. Allow adequate room between views for dimensions (because of the limits in page size many of the drawings in the book are crowded closer together than would be done on regular working drawings).

Make a little preliminary freehand sketch on scratch paper for arrangement; then follow a systematic order of working. *First*, lay off the sheet and border; *second*, decide what scale to use; *third*, draw the center lines or base lines for each view and on these block in the principal dimensions; *fourth*, finish the projections, carrying the views along together, projecting from one to another.

Work lightly with sharp pencil and do not erase overrunning lines until the problem is finished. For a finished pencil drawing brighten the outlines and erase unnecessary lines. Refer to paragraph 259 with the accompanying illustration, Fig. 589, for a more detailed explanation of the order of penciling, and to paragraph 261 for the order of inking.

Group I. Projections from Pictorial Views. Probs. 1 to 42.

The approximate net space required for the problem, if drawn to the size given, is added in parenthesis after each specification.

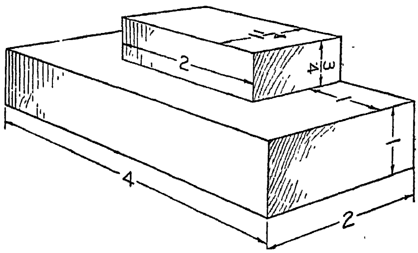


FIG. 245.—Step block.

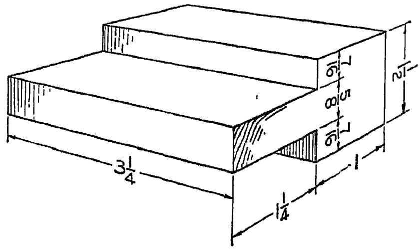


FIG. 246.—Tenon.

1. Fig. 245. Draw the front, top and right side views of the step block (5″ × 7″ space).

2. Fig. 246. Draw the front, top and right side views of the tenon (5″ × 7″ space).

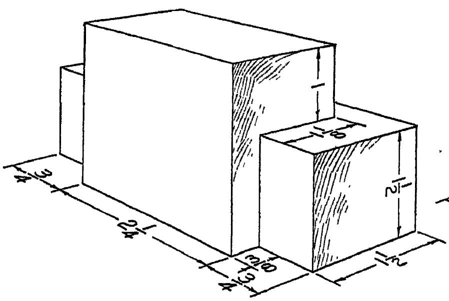


FIG. 247.—Bumper.

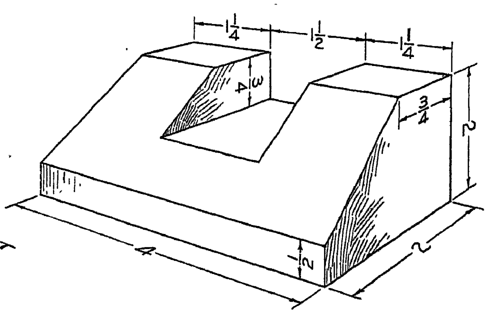


FIG. 248.—Slotted wedge.

3. Fig. 247. Draw three views of the bumper (6″ × 7″ space).

4. Fig. 248. Draw three views of the slotted wedge (5″ × 7″ space).

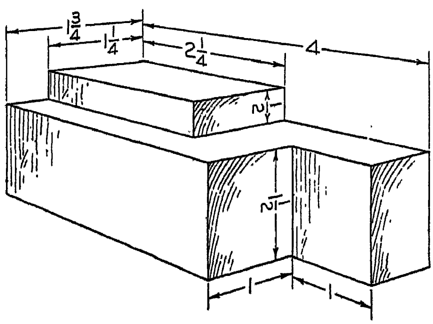


FIG. 249.—Corner block.

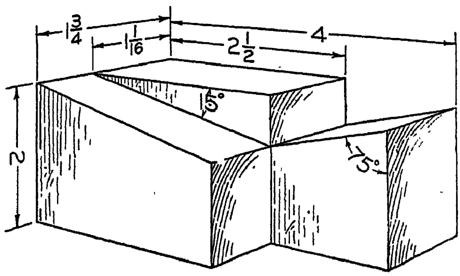


FIG. 250.—Inclined support.

5. Fig. 249. Draw three views of the corner block (5″ × 7″ space).

6. Fig. 250. Draw three views of the inclined support (5″ × 7″ space).

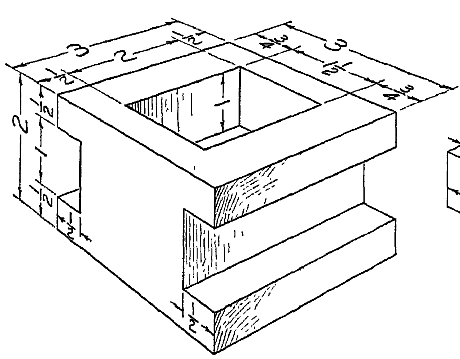


Fig. 251.—Sliding socket.

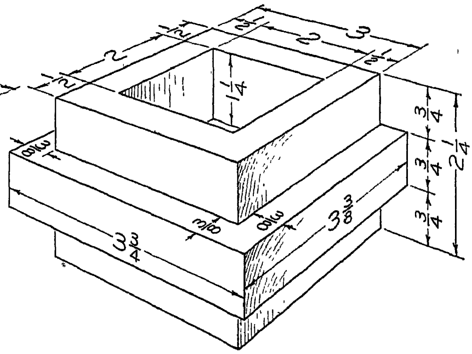


Fig. 252.—Flanged pocket.

7. Fig. 251. Draw three views of the sliding socket (6″ × 7″ space).
8. Fig. 252. Draw three views of the flanged pocket (7″ × 8″ space).

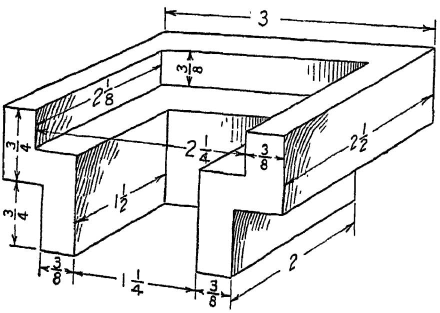


Fig. 253.—Saddle bracket.

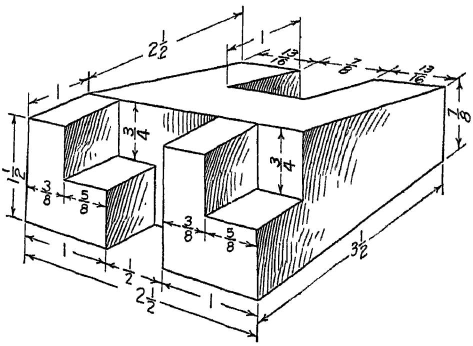


Fig. 254.—Wedge block.

9. Fig. 253. Draw three views of the saddle bracket (5″ × 7″ space).
10. Fig. 254. Draw three views of the wedge block (6″ × 7″ space).

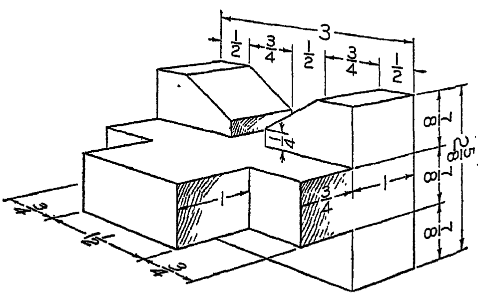


Fig. 255.—Vee rest.

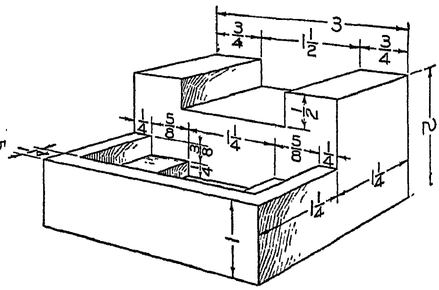


Fig. 256.—Latch pocket.

11. Fig. 255. Draw three views of the Vee-rest (7″ × 7″ space).
12. Fig. 256. Draw three views of the latch pocket (6″ × 7″ space).
13. Fig. 257. Draw three views of the corner stop (5″ × 7″ space).
14. Fig. 258. Draw three views of the locating saddle (5″ × 7″ space).
15. Fig. 259. Draw three views of the leveling wedge (7″ × 11″ space).

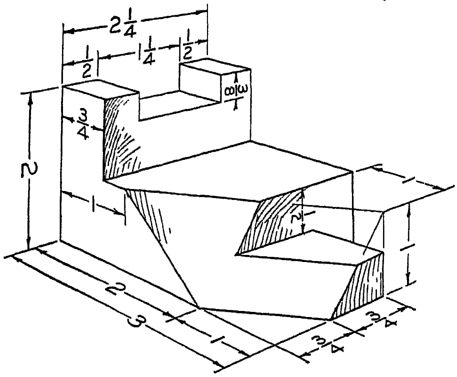


Fig. 257.—Corner stop.

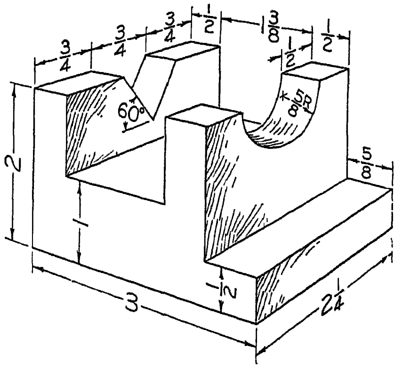


Fig. 258.—Locating saddle.

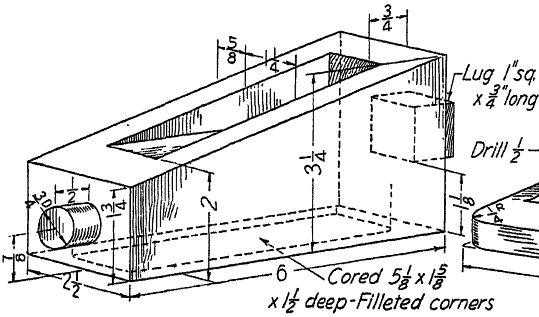


Fig. 259.—Leveling wedge.

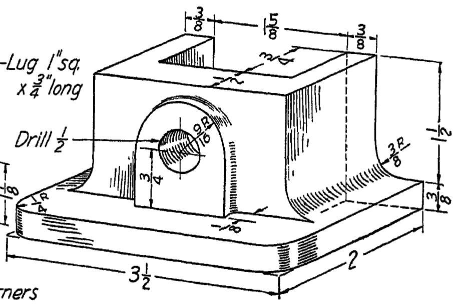


Fig. 260.—Guide base.

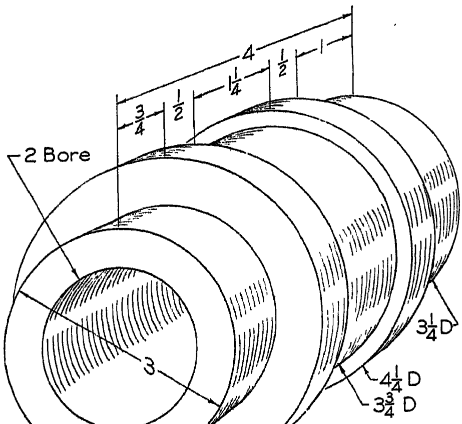


Fig. 261.—Flanged collar.

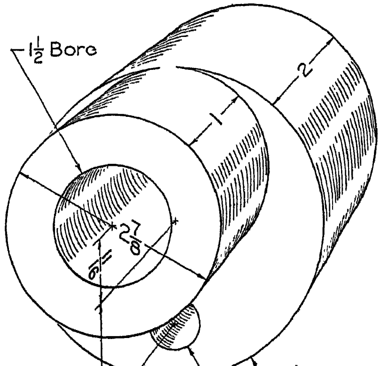


Fig. 262.—Eccentric.

16. Fig. 260. Draw three views of the guide base (5″ × 7″ space).
17. Fig. 261. Draw two views of the flanged collar (5″ × 9″ space).
18. Fig. 262. Draw two views of the eccentric (5″ × 8″ space).

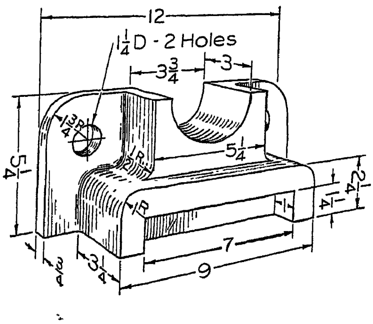


FIG. 263.—Bearing rest.

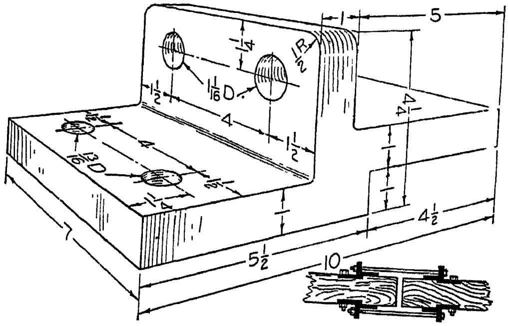


FIG. 264.—Splice plate.

19. Fig. 263. Draw three views of bearing rest (scale to suit).

20. Fig. 264. Draw three views of splice plate (scale to suit).

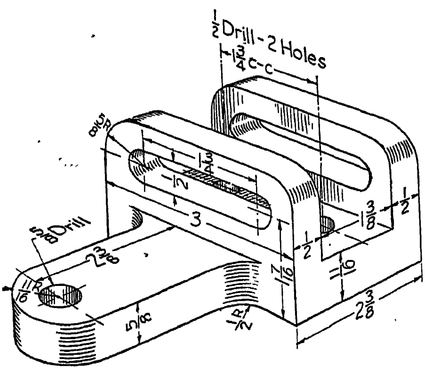


FIG. 265.—Adjusting bracket.

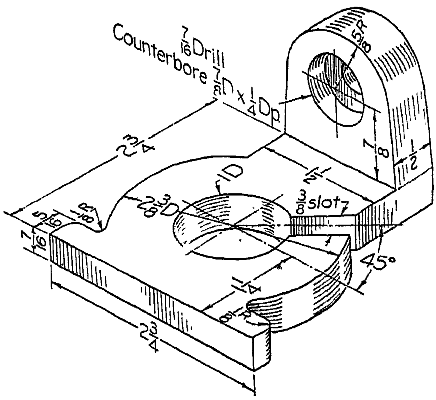


FIG. 266.—Switch base.

21. Fig. 265. Draw three views of adjusting bracket (6″ × 9″ space).

22. Fig. 266. Draw three views of switch base ($5\frac{1}{2}$″ × 7″ space).

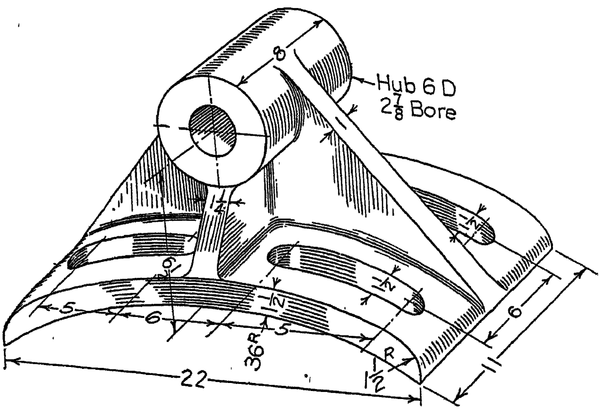


FIG. 267.—Brake shoe.

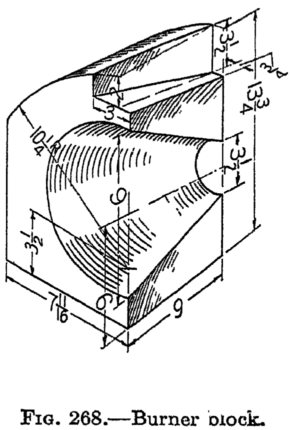


FIG. 268.—Burner block.

23. Fig. 267. Draw two views of brake shoe (scale to suit).

24. Fig. 268. Draw three views of burner block (scale to suit).

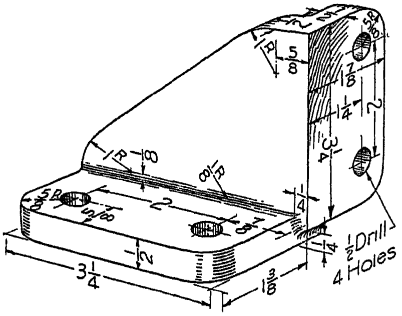


FIG. 269.—Angle bracket.

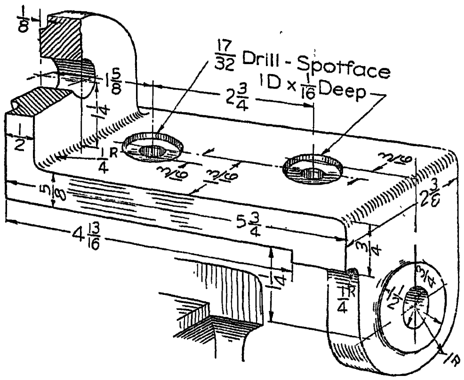


FIG. 270.—Stop base.

25. Fig. 269. Draw three views of angle bracket (8″ × 8″ space).
26. Fig. 270. Draw three views of stop base (9″ × 11″ space).

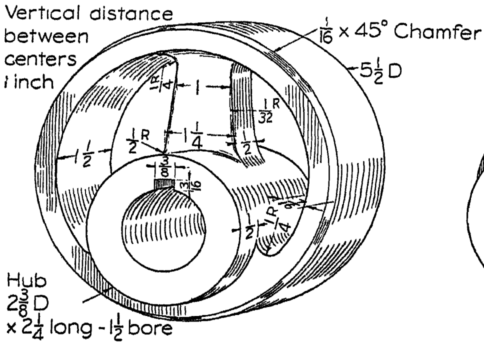


FIG. 271.—Eccentric.

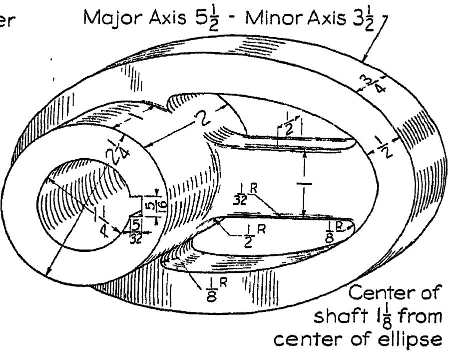


FIG. 272.—Elliptical cam.

27. Fig. 271. Draw two views of eccentric (6″ × 9″ space).
28. Fig. 272. Draw two views of elliptical cam (6″ × 9″ space).

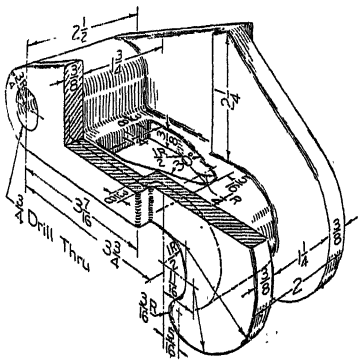


FIG. 273.—Pawl hook.

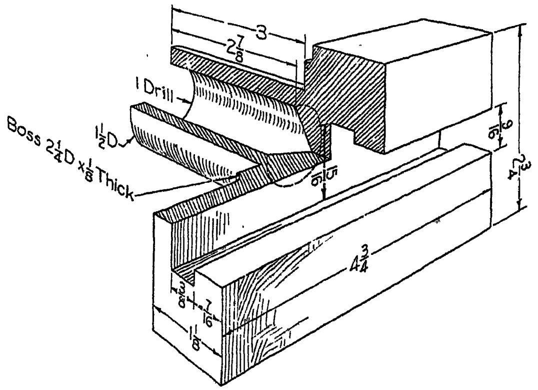


FIG. 274.—Slotted crank.

29. Fig. 273. Draw two views of pawl hook (9″ × 9″ space).
30. Fig. 274. Draw three views of slotted crank (8″ × 8″ space with side view in second position).

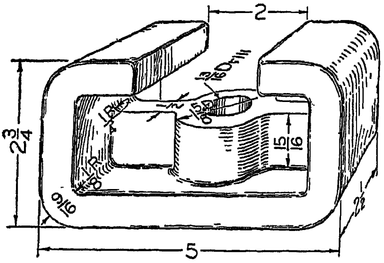


Fig. 275.—Clamp frame.

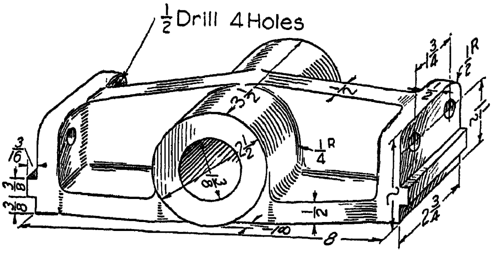


Fig. 276.—Truss bearing.

31. Fig. 275. Draw three views of clamp frame (8″ × 10″ space).

32. Fig. 276. Draw three views of truss bearing (7″ × 13″ space).

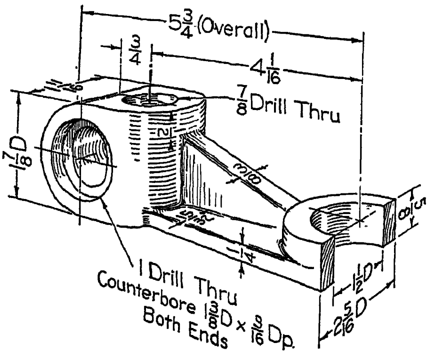


Fig. 277.—Shifter fork.

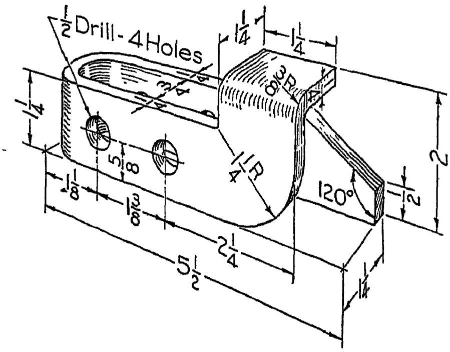


Fig. 278.—Mounting bracket.

33. Fig. 277. Draw two views of shifter fork (6″ × 8″ space).

34. Fig. 278. Draw three views of mounting bracket (7″ × 10″ space).

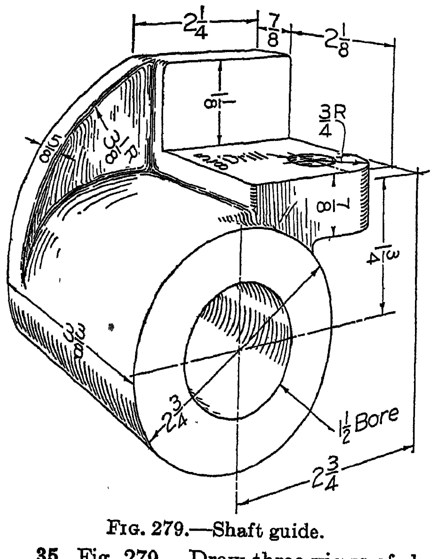


Fig. 279.—Shaft guide.

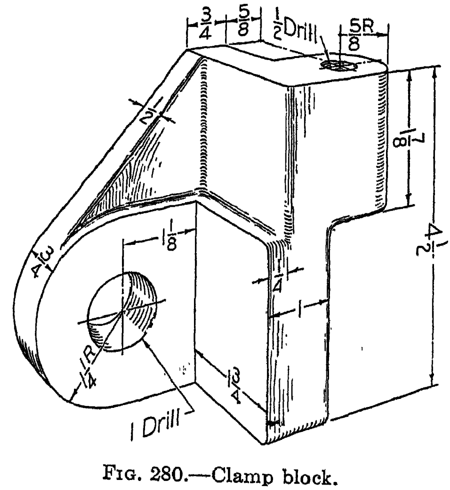


Fig. 280.—Clamp block.

35. Fig. 279. Draw three views of shaft guide (10″ × 11″ space).

36. Fig. 280. Draw three views of clamp block (9″ × 9″ space).

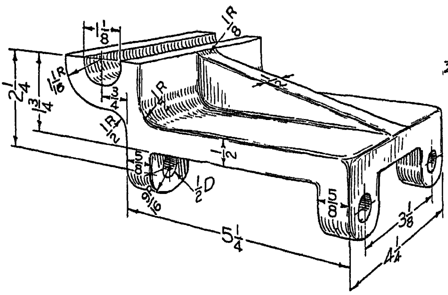


FIG. 281.—Hinged bearing.

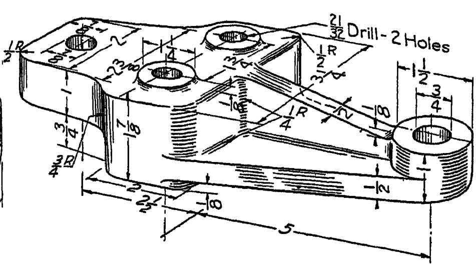


FIG. 282.—Clamp lever.

37. Fig. 281. Draw three views of hinged bearing (9″ × 12″ space).
38. Fig. 282. Draw two views of clamp lever (7″ × 10″ space).

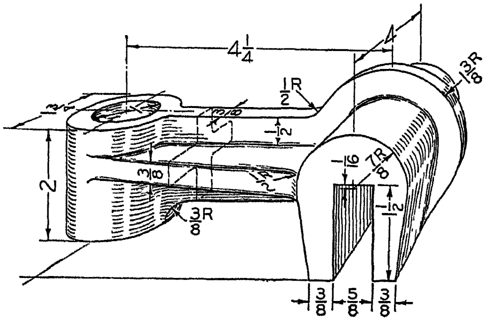


FIG. 283.—Sliding hook.

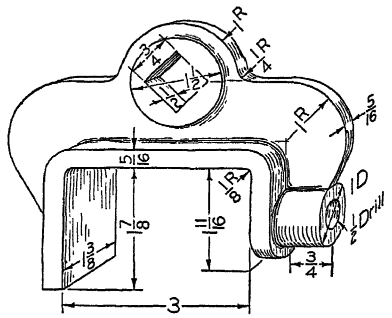


FIG. 284.—Clamp.

39. Fig. 283. Draw three views of sliding hook (9″ × 12″ space).
40. Fig. 284. Draw two views of clamp (5″ × 9″ space).

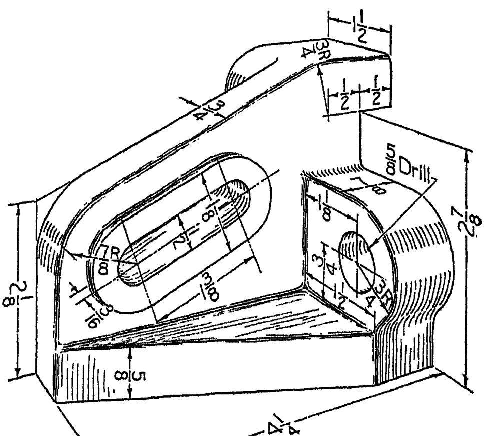


FIG. 285.—Angle connector.

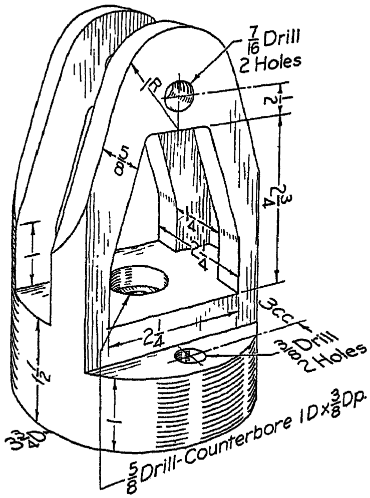


FIG. 286.—Plastic switch base.

41. Fig. 285. Draw three views of angle connector (8″ × 10″ space).
42. Fig. 286. Draw three views of plastic switch base (11″ × 9½″ space).

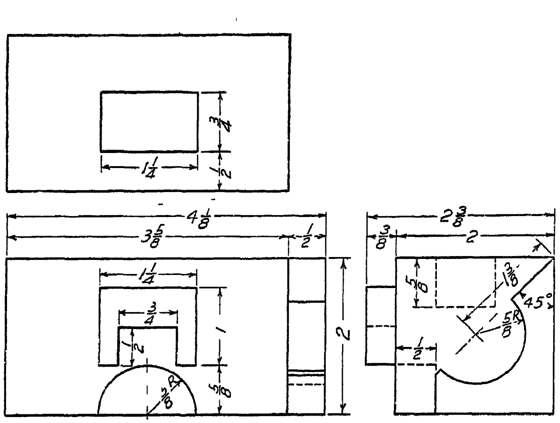


FIG. 287.—Projection study.

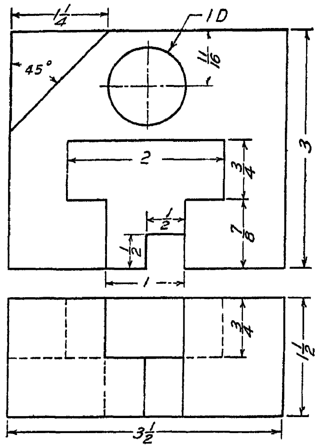


FIG. 288.—Projection study.

Group II. Views to Be Supplied. Probs. 43 to 61.

43. Fig. 287. Draw the views given, completing the top view from information given on front and side views. Carry the three views along together.

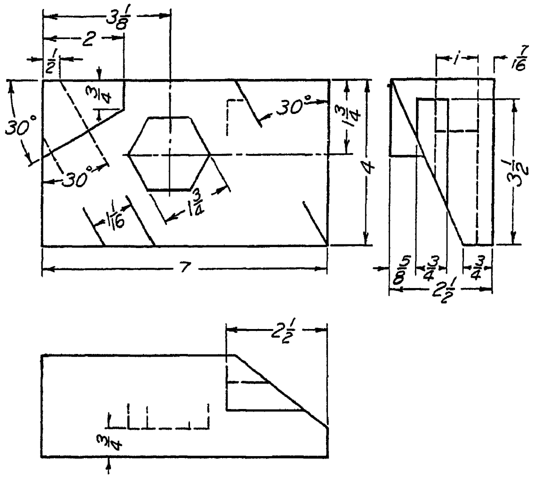


FIG. 289.—Projection study.

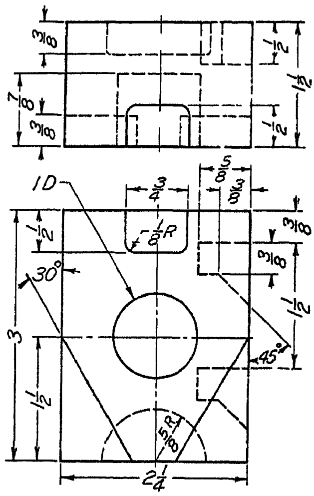


FIG. 290.—Projection study.

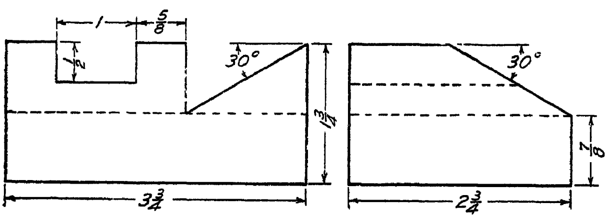


FIG. 291.—Projection study.

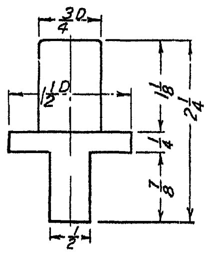


FIG. 292.—Shifter shoe.

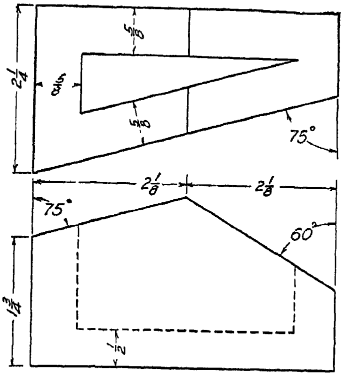


FIG. 293.—Wedge block.

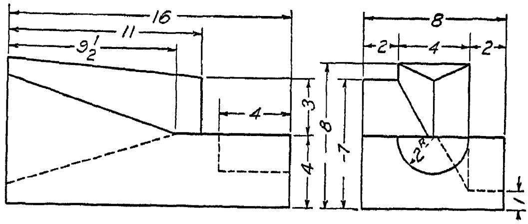


FIG. 294.—Bit point-forming die.

44. Fig. 288. Given top and front views of block. Required, top, front and right side views. See that hidden lines start and stop correctly.

45. Fig. 289. Complete the three views given.

46. Fig. 290. Given front and top views. Add side view.

47. Fig. 291. Given front and right side views. Add top view.

48. Fig. 292. Given front view of shifter shoe. Required front, top and right side views. Note that D is the abbreviation for diameter.

49. Fig. 293. Given top and front views. Add right side view.

50. Fig. 294. Given front and side views. Add top view.

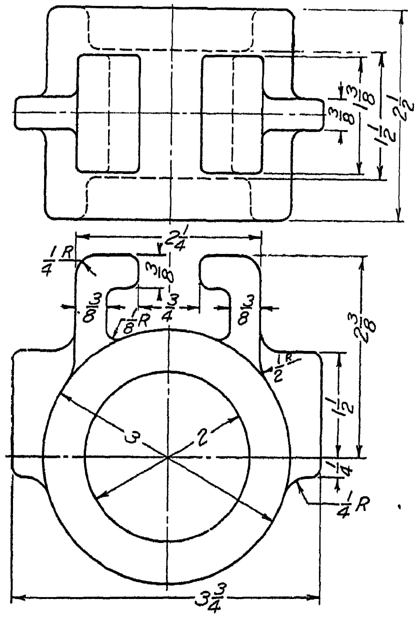


FIG. 295.—Forging blank.

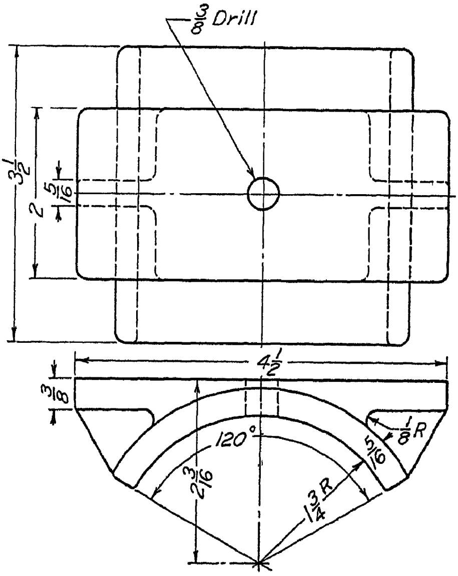


FIG. 296.—Spring saddle.

51. Fig. 295. Given front and top views. Add side view.

52. Fig. 296. Given front and top views. Add side view.

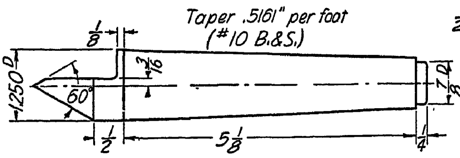


Fig. 297.—Grinder tailstock center.

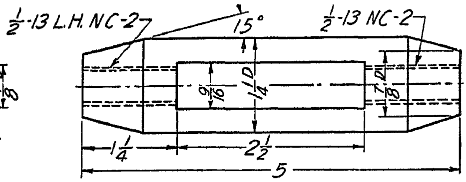


Fig. 298.—Turnbuckle.

53. Fig. 297. Given front view. Add top and left side views.

54. Fig. 298. Given front view. Add top view and side view. For thread symbols and specifications see Chap. XII.

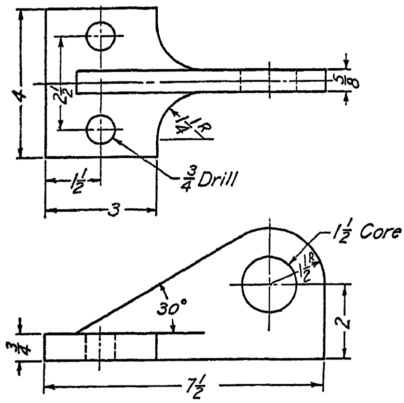


Fig. 299.—Anchor bracket.

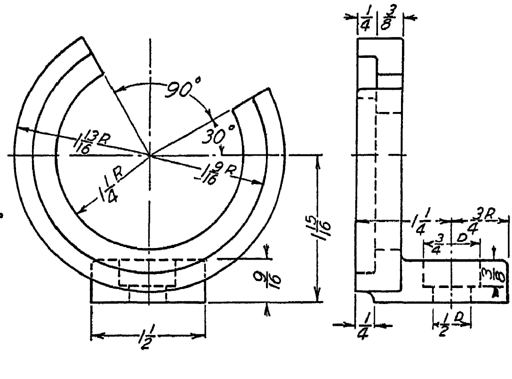


Fig. 300.—Saddle collar.

55. Fig. 299. Given front and top views. Add side view.

56. Fig. 300. Given front and side views. Add top view.

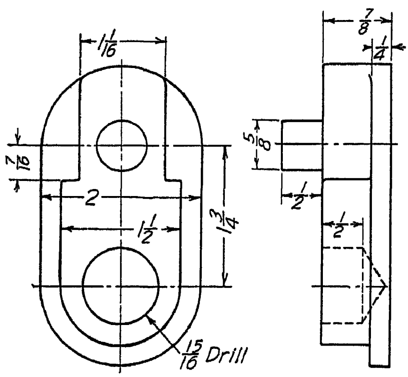


Fig. 301.—Lockplate.

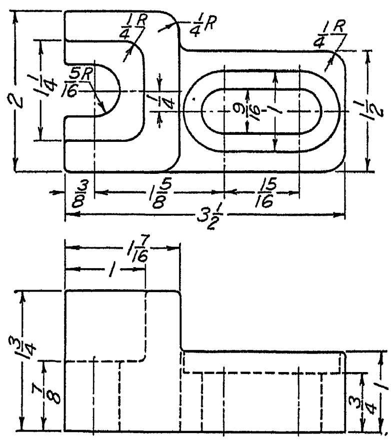


Fig. 302.—Tool holder.

57. Fig. 301. Given front and side views. Draw three views.

58. Fig. 302. Given front and top views. Add both side views.

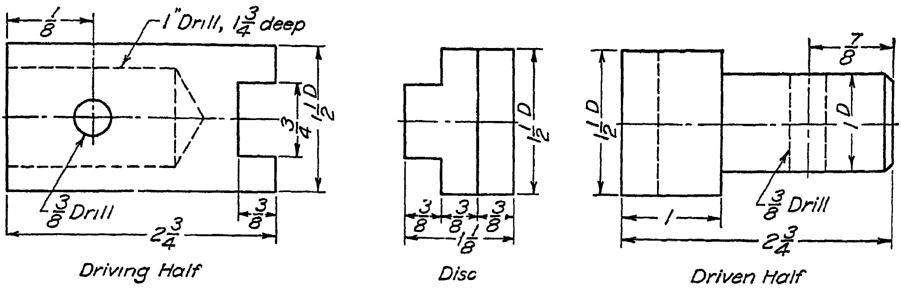


FIG. 303.—Coupling.

59. Fig. 303. Given one view of driving half of coupling. Draw three views.

60. Fig. 303. Given one view of disk and driven half of coupling. Draw three views of each.

60A. Fig. 303. Draw three views of coupling assembled.

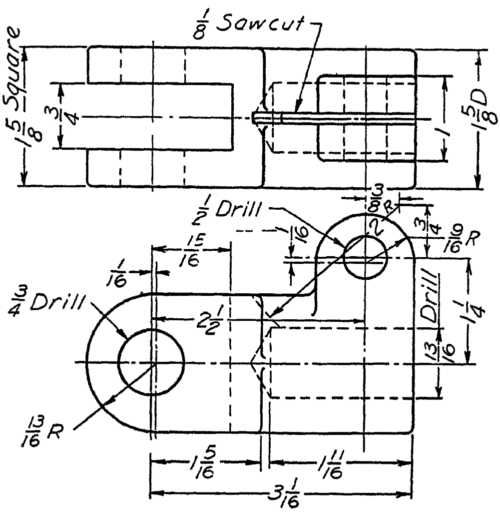


FIG. 304.—Rod yoke.

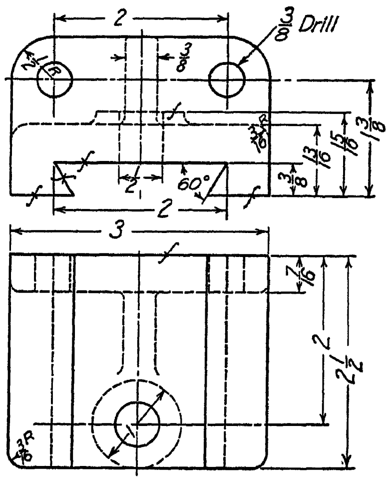


FIG. 305.—Sliding block.

61. Fig. 304. Given front and top views. Add right side view

Group III. Views to Be Changed. Probs. 62 to 69.

This group furnishes a more difficult test of the reader's constructive imagination. These problems are given to develop the ability to visualize the actual piece in space and from this mental picture to draw the required views as they would appear if the object were looked at in the directions specified. Students will find it of much assistance to make a pictorial sketch or perhaps a clay model of the piece before starting the drawing.

62. Fig. 305. Given top and front views. Required new front, top and side views, turning the block around so that the back becomes the front. The rib contour is straight.

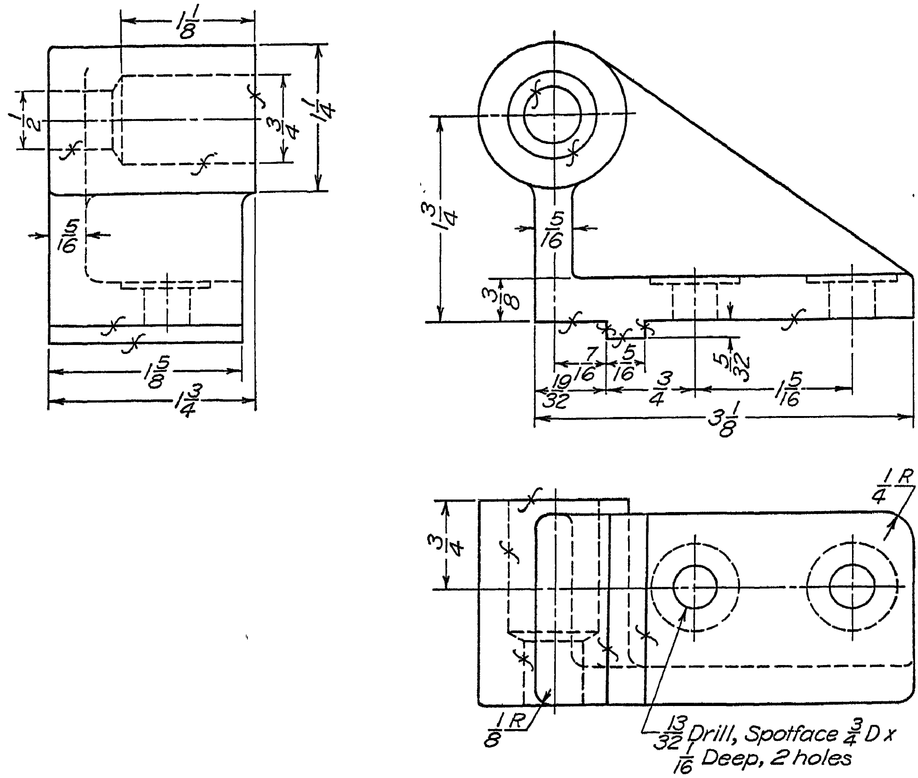


FIG. 306.—Plunger bracket.

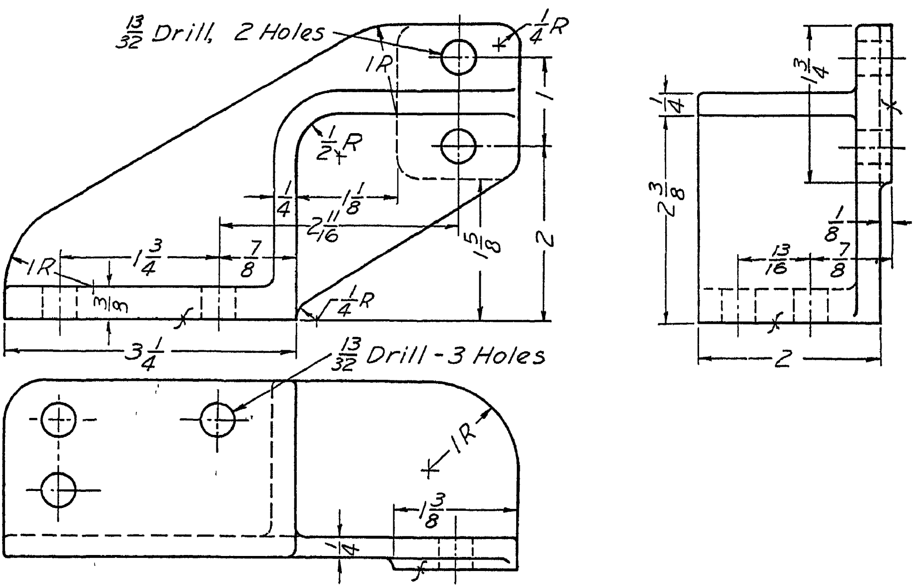


FIG. 307.—Offset bracket.

63. Fig. 306. Given front, left side and bottom views. Draw, front, top and right side.
64. Fig. 307. Given front, right side and bottom views. Draw front, top and left side.

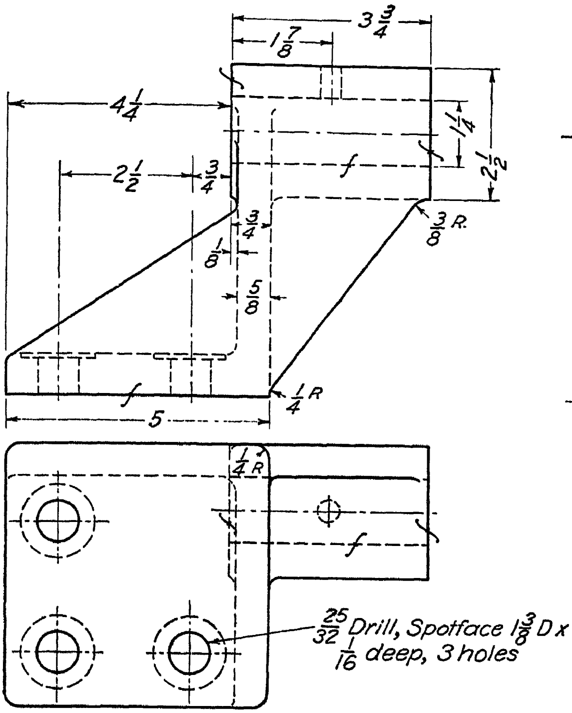


Fig. 308.—Toggle shaft bracket.

65. Fig 308. Given rear, bottom and *left* side views. Draw front, top and right side.

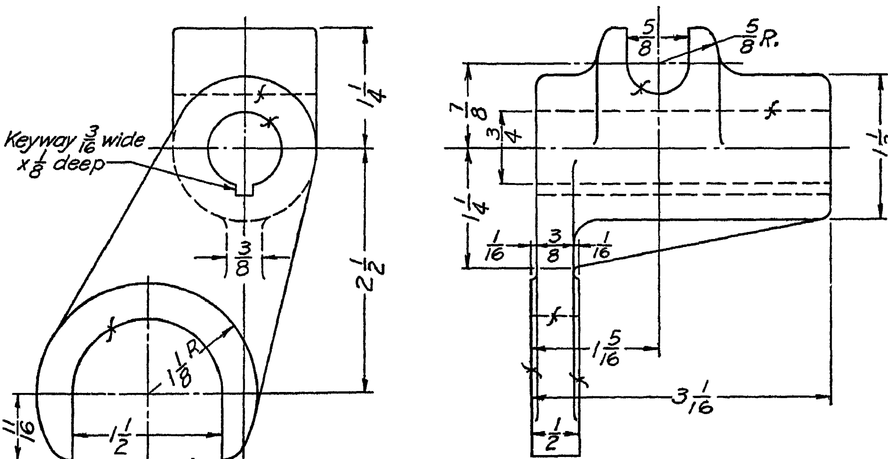


Fig. 309.—Shifter fork

66. Fig. 309. Given front and left side views. Required front, right side and top.

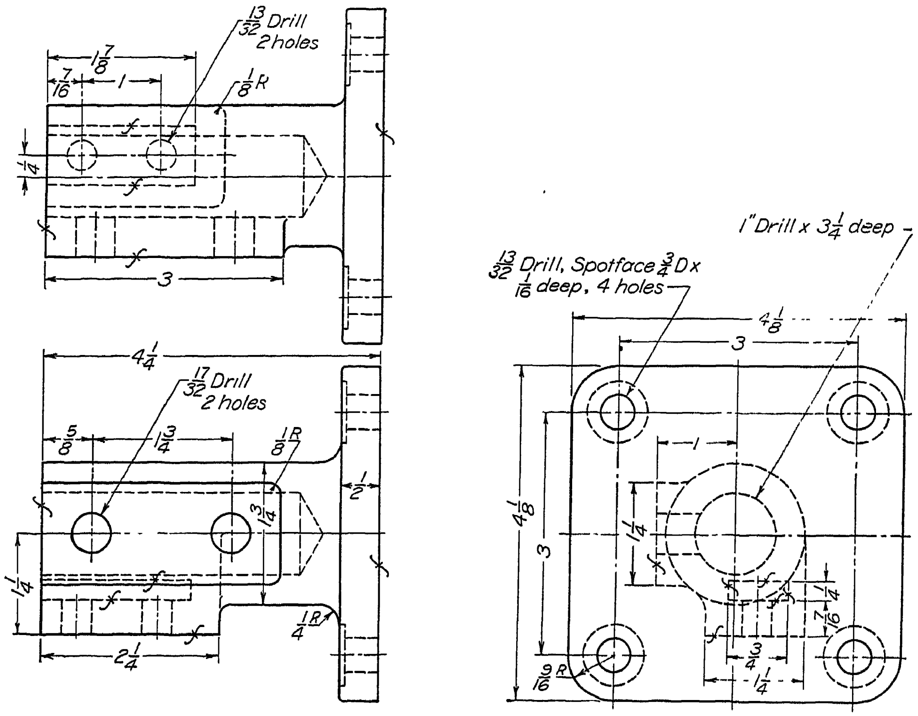


FIG. 310.—Tool base.

67. Fig. 310. Given top, right side in second position, and rear views. Required top, front and left side views.

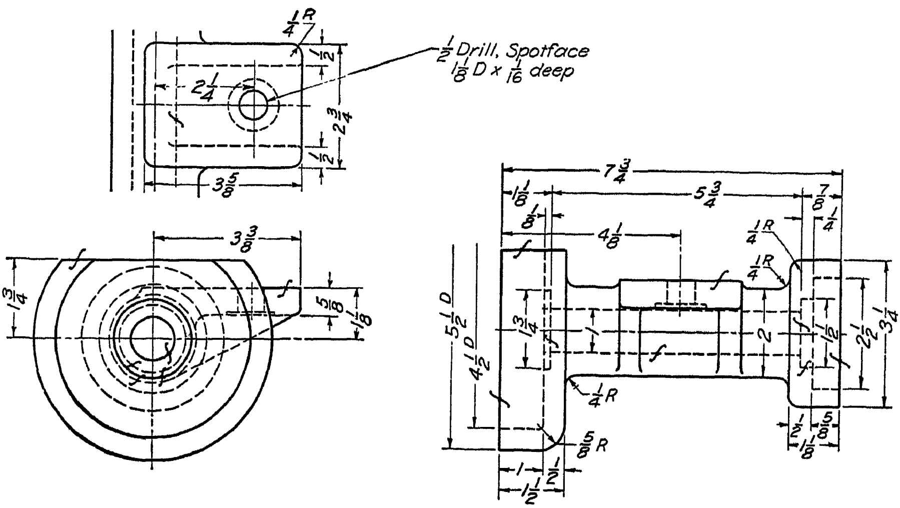


FIG. 311.—Indicator bracket.

68. Fig. 311. Given front and left side views, with a detail of pad. Required front, top and right side views.

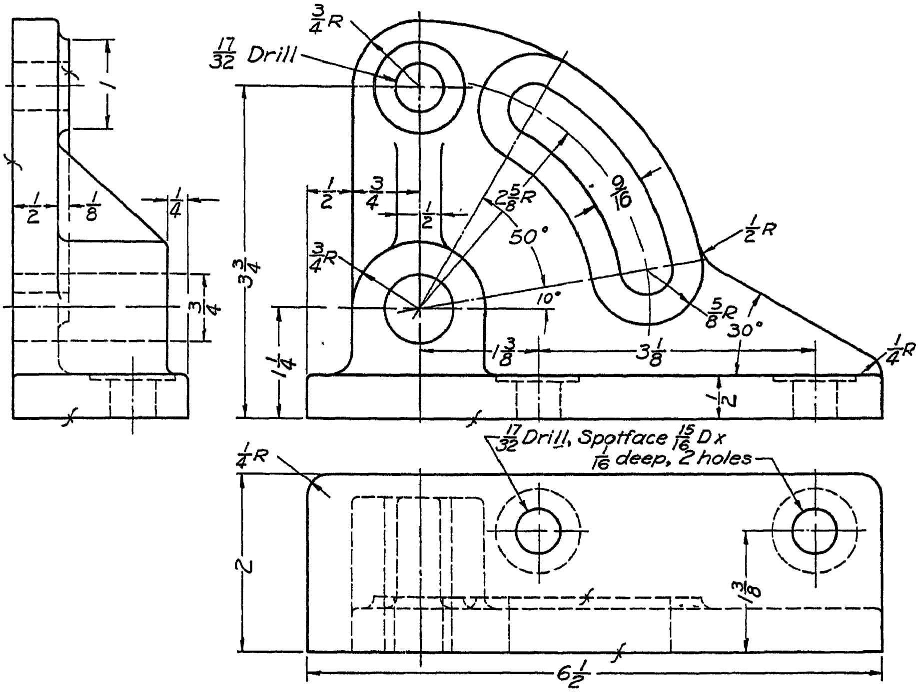


Fig. 312.—Sector bracket.

69. Fig. 312. Given front, left side and bottom views. Required front, right side and top views.

Group IV. Drawing from Memory.

One of the valuable assets of an engineer is a trained memory for form and proportion. The graphic memory may be developed to a surprising degree in accuracy and power by systematic exercises in drawing from memory, and this training may be commenced as soon as a knowledge of orthographic projection has been acquired.

Select an object not previously used, such as one from Figs. 230 and 231 or Figs. 245 to 286; look at it with concentration for a certain time (from 5 seconds to ½ minute or more); close the book and make an accurate orthographic sketch. Check with the original and correct any mistakes or omissions. Follow with several different figures. The next day allow a 2-second view of one of the objects, and with this as a reminder, repeat the orthographic views of the previous day. As indicated in Chap. XXI, paragraph 361, this practice may be varied in several ways after one has become proficient in sketching. If continued faithfully it will strengthen wonderfully the power of observation.

Group V. Volume and Weight Calculations, with Slide Rule.

In calculating the weight of a piece from the drawings it should be divided or broken up into the geometric solids (prisms, cylinders, pyramids, cones) of which it is composed. The volume of each of these shapes should be calculated and these added, or sometimes subtracted, to find the total volume, which multiplied by the weight of the material per unit of volume will give the weight of the object.

A table of weights of materials will be found in the Appendix.

70. Find the weight of the cast-iron step block, Fig. 245.

71. Find the weight of the wrought-iron bumper, Fig. 247.

72. Find the weight of the brass slotted wedge, Fig. 248.

73. Find the weight of the brass sliding socket, Fig. 251.

74. Find the weight of the malleable-iron locating saddle, Fig. 258.

75. Find the weight of the aluminum guide base, Fig. 260.

76. Find the weight of the cast-steel eccentric, Fig. 262.

77. Find the weight of the aluminum block, Fig. 291.

78. Find the weight of the brass shifter shoe, Fig. 292.

79. Find the weight of the bronze lock plate, Fig. 301.

80. Find the weight of the cast-iron toggle-shaft bracket, Fig. 308.

These are given as examples of problems whose weights may be found. Many other problems, such as the flywheel, Fig. 610, may be used.

CHAPTER VIII

AUXILIARY PROJECTION

115. A surface is shown in its true shape when projected on a plane parallel to it. As the majority of objects are rectangular they may be placed with their three principal faces parallel to the three planes of projection and be fully described by the principal views. Sometimes however, the object will have one or more inclined faces whose true shape it is desirable

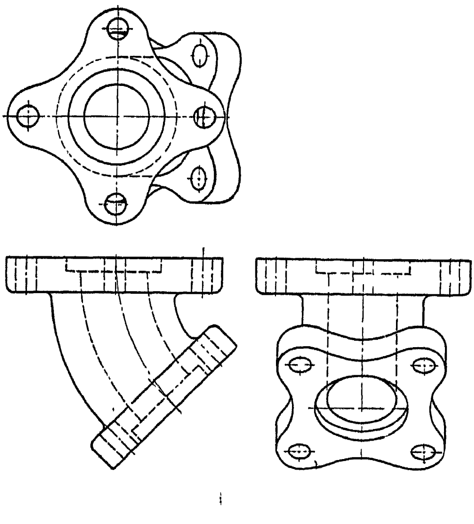


FIG. 313.—Front, top and right side views.

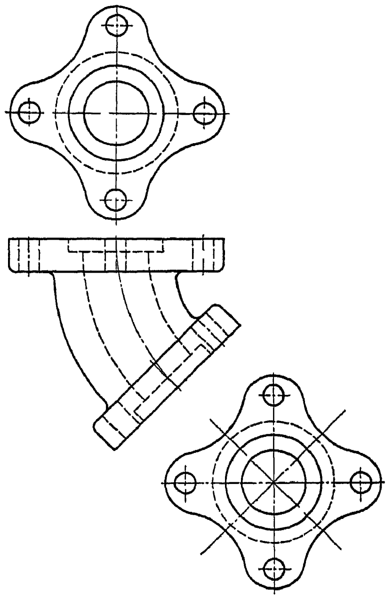


FIG. 314.—Front, partial top and auxiliary views.

or necessary to show, especially if irregular in outline. An example is the flanged angle in Fig. 313, a casting having an irregular inclined face which not only cannot be shown in true shape in either of the principal views but also is difficult to draw in foreshortened position. An easier and more practical selection of views for this piece is shown in Fig. 314, using what is known as an **auxiliary view,** *looking straight against the inclined face*, that is, imagining a projection on an extra or auxiliary plane parallel to the face, and revolving it into the plane of the paper.

116. Definition.—*An auxiliary view is a projection of an object on a plane which is perpendicular to one of the principal planes of projection and inclined*

to the other two. Thus the auxiliary plane would show as an edge view on the plane to which it is perpendicular. Since the reason for using this kind of view is to obtain the true shape of a slanting surface, in practical drafting an auxiliary plane is always placed parallel to the slanting surface, hence the edge view of this plane will be parallel to the edge view of the slanting

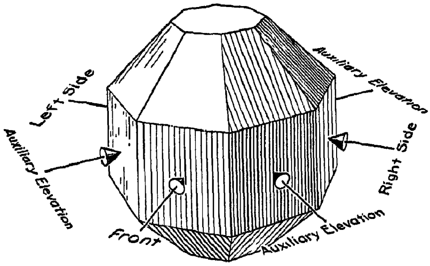


FIG. 315.—Directions from which auxiliary elevations are taken.

surface. The auxiliary plane is revolved into the plane of the paper by considering it to be hinged to the plane to which it is perpendicular. Note that if an inclined face does not show in edge view on one of the three prin-

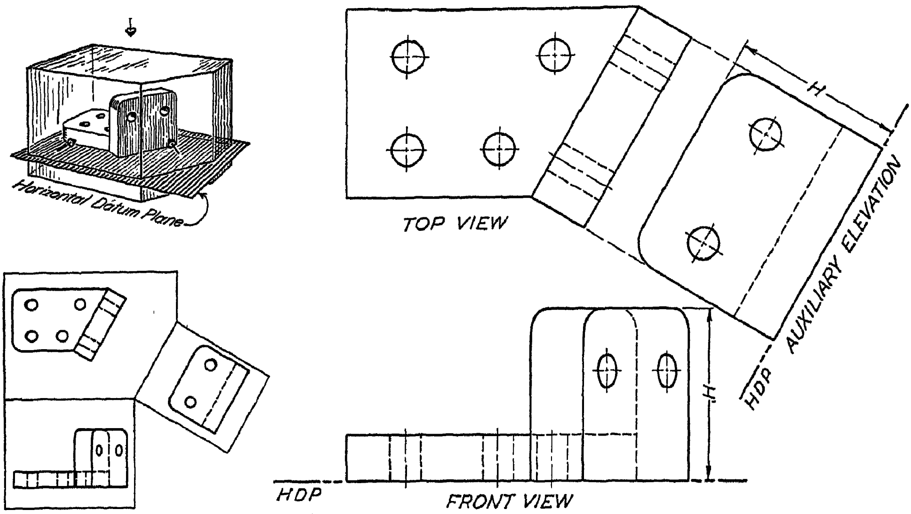


FIG. 316.—Auxiliary elevation.

cipal planes it is known as an *oblique* surface, and two operations will be required to find its true shape, as described later in paragraph 124.

In projecting an object on an auxiliary plane the inclined surface will be shown in its true shape but the other faces of the object will evidently be foreshortened, and in practical work these foreshortened parts are usually omitted, as in Fig. 314. However, the exercise of drawing a complete view aids the student in understanding the subject.

117. Auxiliary Elevations.—There are three kinds of auxiliary views: first, *auxiliary elevations*, made on planes which are perpendicular to the

horizontal plane and inclined to the other two principal planes, or in other words the kind of views that would be seen if one walked around the object, starting at the position from which the front view is seen and following a horizontal circle, as in Fig. 315. In this trip the observer would successively pass the points from which the right side view, the rear view, the left side view and finally again the front view would be seen. A view from any other point on the circle would be an auxiliary elevation. An auxiliary elevation may thus be taken from the right front, right rear, left rear, or left front directions. On any drawing the front view, or front elevation, shows the *height* of the object. In an auxiliary elevation the observer looks in a horizontal direction, hence the height of any point on the auxiliary elevation will be the same as in the front view. Thus all height measurements will be made from some fixed horizontal reference plane called a "datum plane."

In Fig. 316 the right end of the piece is at an angle to the front and side planes and perpendicular to the horizontal plane, thus its edge would show in the top view, but its true shape would not appear in either the front or side views. An auxiliary elevation taken as if looking directly at the surface would show the true shape. Assume the horizontal plane of the base of the object to be the datum plane *HDP*, draw the edge of the datum plane for the auxiliary view parallel to the top view of the edge of the inclined surface, project the points of the inclined surface from the top view perpendicular to the datum plane and transfer the necessary heights from the front view. The auxiliary view of the base is not completed, as it is fully described by the front and top views.

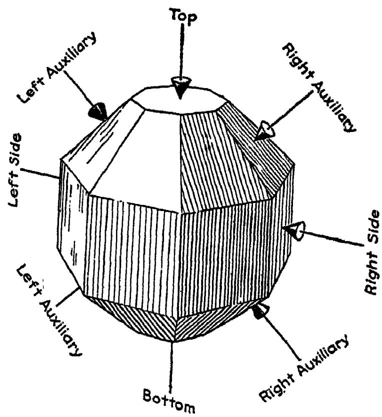


FIG. 317.—Directions from which right and left auxiliaries are taken.

118. Right and Left Auxiliary Views.—The second type, which occurs much more frequently, is the right or left auxiliary view, made on planes perpendicular to the front plane but inclined to the horizontal plane, the sort of views that may be imagined if one were to travel around the object in a vertical circle parallel to the front plane. Starting at the point from which the right side view would be seen, move up counterclockwise until directly above the object, from which point the top view would be seen, Fig. 317. A view taken anywhere between these two stops would be a right-auxiliary view. Continuing, any view from the circle between the top view and the left-side view would be a left-auxiliary view. Similarly, right and left auxiliaries can be imagined from the lower half of the frontal circle, as indicated on the figure. The depth from front to back of all these auxiliary

views is exactly the same as that of the top and side views. Thus all depth measurements on right and left auxiliary views would be made from a frontal datum plane *FDP*. Figure 318 gives the top and front views of a bent plate

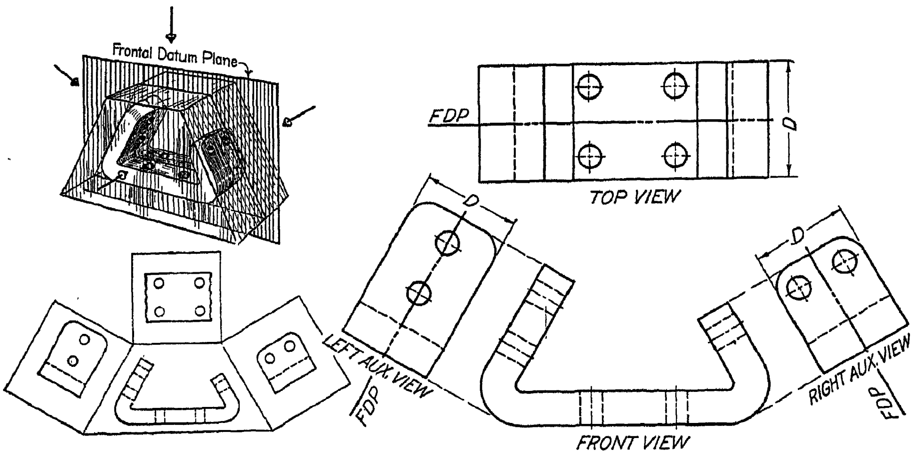


FIG. 318.—Right and left auxiliaries.

and the use of both right and left auxiliary part views to show the shape and drilling of the ends. The auxiliary views are projected from the front view and their depths taken from the top view, measuring on each side of a frontal datum plane through the center of the top view.

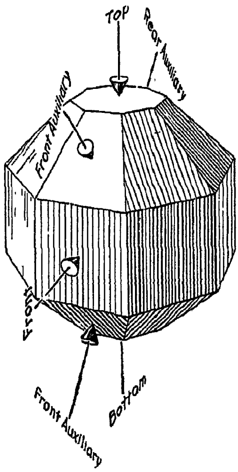


FIG. 319.—Directions from which front and rear auxiliaries are taken.

119. Front and Rear Auxiliary Views.—The third type is that of front and rear auxiliary views, made on planes perpendicular to the side or profile plane. For such views the locus of the viewpoints is the profile circle that passes through the viewpoints for the front, top, rear and bottom views, as illutrated pictorially in Fig. 319. Figure 320 shows the use of a partial front auxiliary view projected from the side view, together with a top view and partial front view to describe the piece illustrated. The datum plane will be a profile plane whose edge shows on the front and top views, *PDP*, and since the piece is symmetrical it is taken through the center. Thus measurements are taken from the front view and transferred to each side of the datum plane on the auxiliary view.

Note that an auxiliary elevation must always be projected from the *top* view, a right or left auxiliary view from the *front* view and a front or rear auxiliary view from the *side* view.

120. Use of Auxiliary Views.—An auxiliary view not only shows the shape of an inclined part to better advantage but often saves making one or more of the principal views. A second and very important use of an auxiliary view is in the case where a principal view will have some part in a foreshortened position, which cannot be drawn without first constructing an auxiliary view in its true shape, from which the part can be projected back

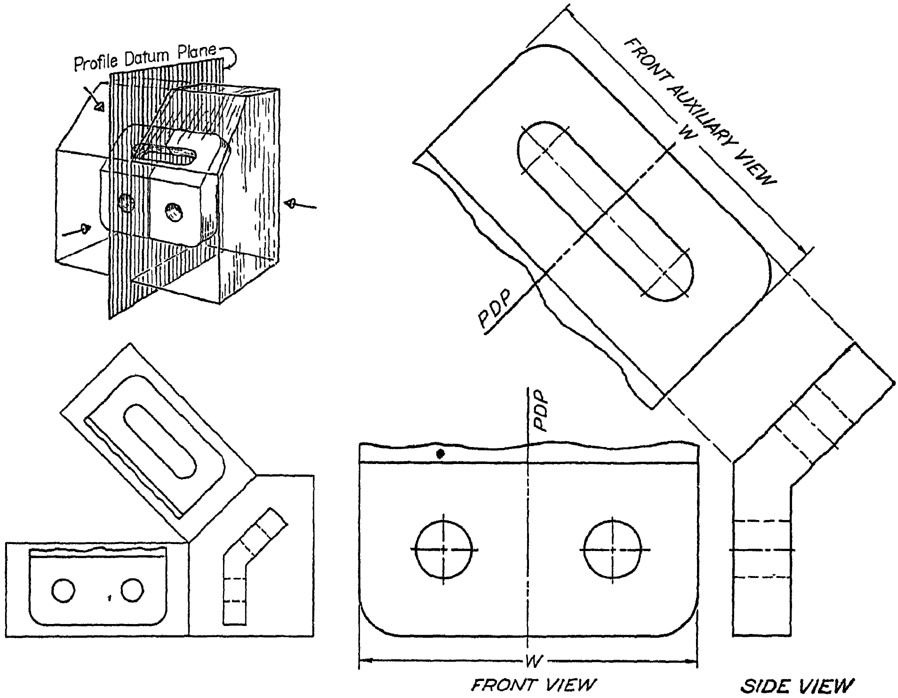


FIG. 320.—Front auxiliary view.

to the principal view. Figure 321 is an illustration of this application. In practical work extensive use is made of auxiliary views. They are generally only partial views showing that part of the object which is parallel to the auxiliary plane, as in Figs. 316, 318 and 320, where nothing would be gained

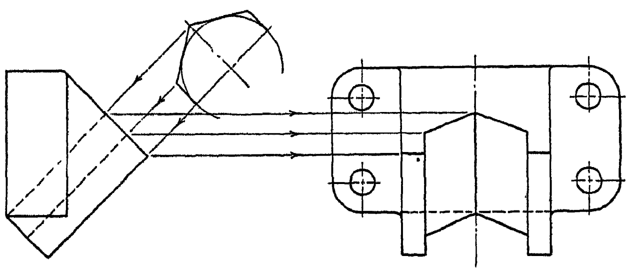


FIG. 321.—Use of constructional auxiliary for completing front view.

by projecting the whole piece. As a further example, a casting as pictured in Fig. 322 would be drawn as shown, making both the auxiliary views and top view as partial views. Figure 323 is an example of a dimensioned drawing with a right auxiliary view, making a top view, and hidden lines in the

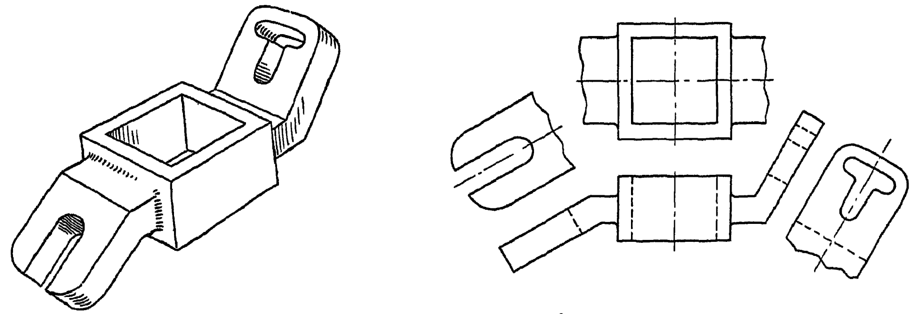


FIG. 322.—Use of part views.

left-side view unnecessary. An auxiliary view may be placed at any convenient distance from the view from which it is projected.

121. To Draw an Auxiliary View.—The key to drawing an auxiliary view easily and quickly is to locate and draw the edge view of the datum plane on the principal view, then locate and draw it for the auxiliary view.

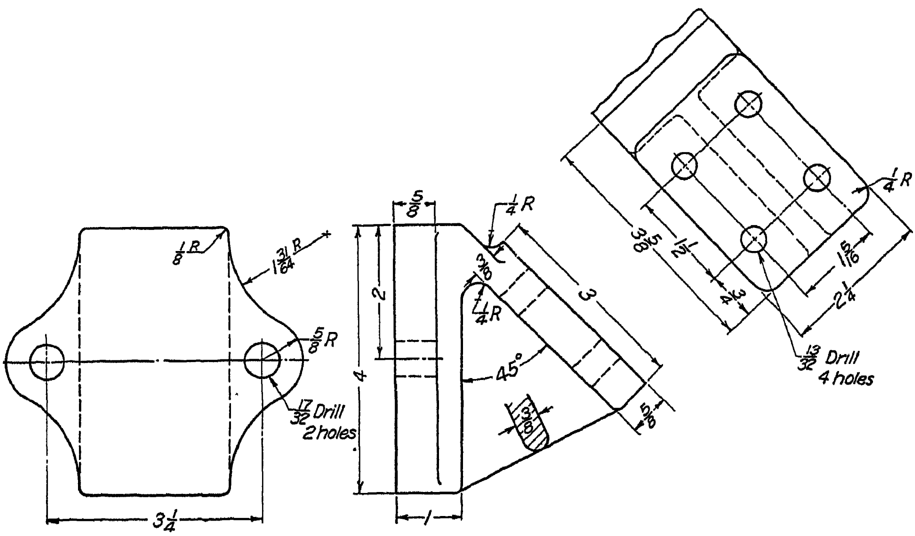


FIG. 323.—Working drawing with auxiliary view. (Strut base.)

For an **auxiliary elevation,** *first,* draw the edge of the horizontal datum plane from which to measure heights, on the front view. This may be taken anywhere, above or below or through the view. For an object standing on a base the bottom plane face of the base is often taken as the datum plane, as *HDP* in Fig. 316. If the front view is symmetrical about a horizontal

center line as in Fig. 324*A*, the datum plane is taken through the center. *Second,* draw the edge view of the datum plane for the auxiliary view parallel to the top view of the face to be shown and at a convenient distance from it, Fig. 324*B*. *Third,* project points of the object from the top view, perpendicular to the datum plane of the auxiliary view *C*, measure their distances H, H_1 from the datum plane on the front view *D* and transfer these measurements with dividers or scale to the auxiliary view, measuring from the auxiliary datum plane. Complete the drawing as illustrated at *E* and *F*.

Note that any measurement made *toward* the top view is transferred *toward* the top view. Note also in Fig. 324 that the front view could not be completed without using the auxiliary view. To get the front view of the circle arcs, whose true shape shows on the auxiliary view, points are selected

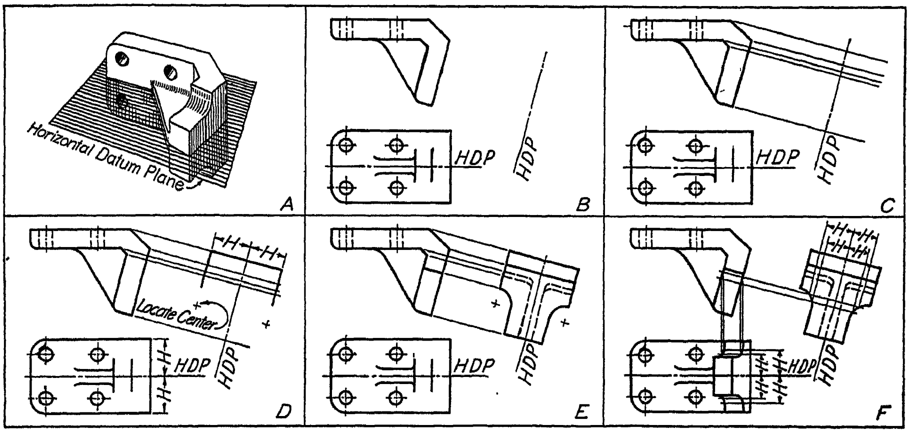


Fig. 324.—Stages in drawing an auxiliary elevation.

on the auxiliary view, projected back to the top view and thence down to the front view. On these projectors the heights H, H_1 are transferred from the auxiliary view to find the corresponding points in the front view.

122. To Draw a Right Auxiliary View.—The datum plane for a right or left auxiliary view will be a frontal plane whose edge *FDP* shows in the top view. If the top view is symmetrical it will be most convenient to pass the datum plane through the center of the piece. If the object is not symmetrical the datum plane may be located on the back face of the object and the view carried on as illustrated progressively in Fig. 325. Draw the datum plane *FDP* for the auxiliary view, parallel to the slanting face of the front view, Fig. 325*B*. Project each point of this face by drawing projecting lines from the front view perpendicular to the datum plane *C*. The depth of the auxiliary view will be the same as the depth of the top view. Thus for each point measure its depth from the datum plane on the top view and lay off this distance from the datum plane on the auxiliary view, as at *D*. Notice that the points are in front of the datum plane on the top view and

therefore are measured toward the front on the auxiliary view. Complete the auxiliary view as at *E*. Note again that the top view of the notch was not finished until after the auxiliary view was made, *F*.

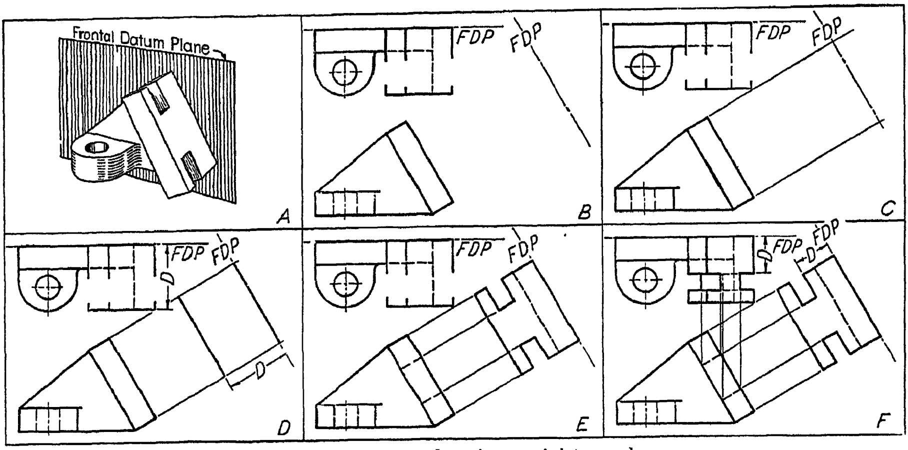


FIG. 325.—Stages in drawing a right auxiliary.

Obviously a *left auxiliary* view would require the same steps reversed left for right.

123. To Draw a Front or Rear Auxiliary View.—As a front or rear auxiliary view is always projected from the side view, there must be a side view as well as a front view from which to work in drawing this type. There

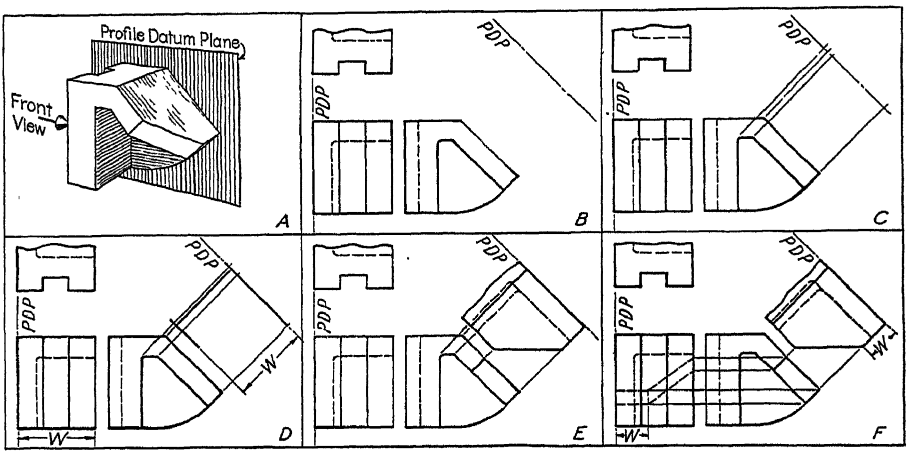


FIG. 326.—Stages in drawing a rear auxiliary.

may of course be a top view also. The datum plane will be a profile plane whose edge will show on the front view (and also on the top view). If the front view is symmetrical about a vertical center line, draw the datum plane *PDP* through the center, otherwise at the right or left, as in Fig. 326*A*. Locate the datum plane for the auxiliary view parallel to the slanting face

in the side view, project the points from the side view perpendicular to the datum plane, transfer to the auxiliary view the width measurements of each point from the datum plane on the front view, noting that measurements made toward the side view are transferred toward the side view. Study the progressive steps in Fig. 326.

124. Oblique or Double Auxiliary Views.—To find the true shape of an oblique surface, that is, a surface not perpendicular to any one of the principal planes, Fig. 327, two operations are required, *first*, a new view of the object from such a position that the oblique surface is seen as an edge, *second*, an auxiliary view from this new view, showing the true shape.

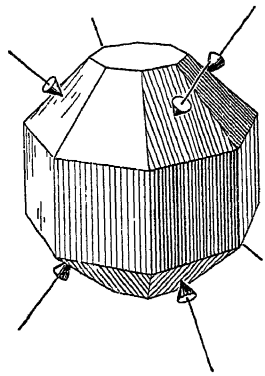


FIG. 327.—Directions from which oblique views are taken.

The definition of an auxiliary view was given as a view on a plane perpendicular to one of the principal planes and inclined to the other two. Thus it will be necessary to view the oblique surface in such a direction that it will project as a line on one of the views, before an auxiliary view to show its true shape can be made. To get this edge view of the surface a first or preliminary auxiliary view must be taken on a plane *perpendicular* to the surface and at the same time perpendicular to one of the principal planes.

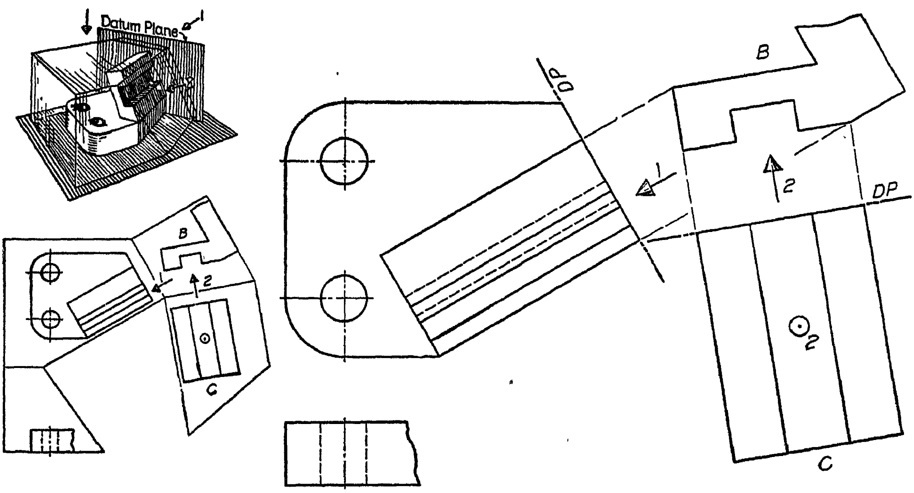


FIG. 328.—Double auxiliary or oblique view.

If in Fig. 328 the oblique surface of the skew guide is looked at in the direction of arrow 1, or, in other words, is projected on the vertical plane *DP* perpendicular to it, the surface would be seen as an edge and the view when revolved up into the plane of the paper will be as at *B*. If from this

position the oblique surface is looked at in the direction of arrow 2, or straight against the surface, its true size will be seen as at C.

Figure 329 illustrates the two operations in progressive steps, showing that an auxiliary elevation was made first, B, looking in a horizontal direction parallel to the line AB of the oblique surface, thus getting the line to project as a point and the oblique surface as a line. Then a second auxiliary view was made looking directly at the required surface. This second auxiliary is made by considering the original top view and the new auxiliary elevation as two regular views, top and front, and discarding the original front view. In following this procedure the reader must orient these two views, thinking of them as straightened up into the more familiar position of front and top

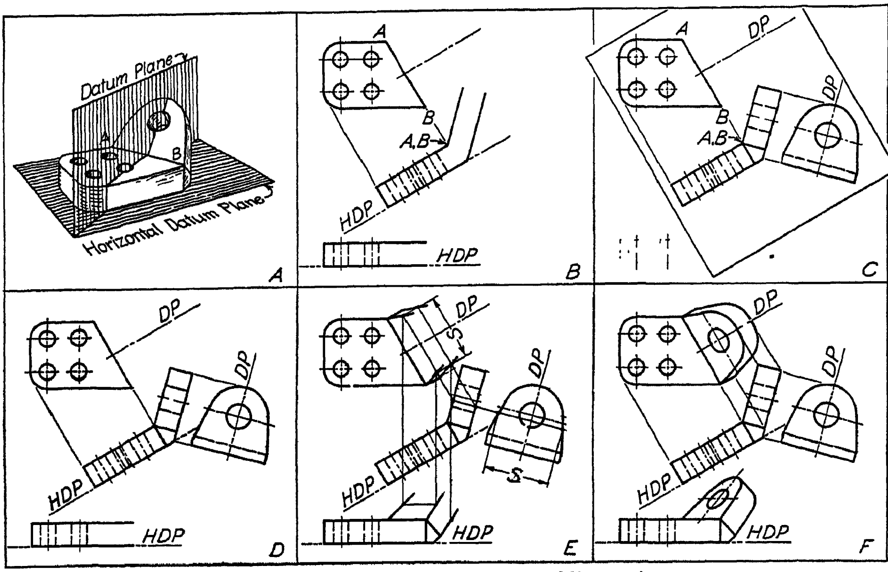


FIG. 329.—Stages in drawing an oblique view.

views, or actually turning the paper, as indicated at C. With the views in this position it is very simple to make a right auxiliary showing the true size of the inclined face, as already explained in paragraphs 118 and 122. This second auxiliary is the oblique view sought. At D the orienting frame shown at C is removed and the completed oblique view shown, with the incomplete top and front views of the piece. E and F of the progressive series illustrate the method of finishing the top and front views, if required, by projecting back from the oblique view. Note that the datum plane for the oblique view is through the center of the lug and perpendicular to the horizontal plane. Select any point P on the oblique view and project it across to the auxiliary view. From this edge view extend a perpendicular projecting line to cross the datum plane at CD. Measure the distance S on the oblique view and mark it on the top view. Project down from the top view to the front view;

measure the height of the point from the horizontal datum plane on the auxiliary view and transfer this distance from the *HDP* on the front view. Carry on this procedure with as many points as necessary.

125. Revolution.—The term "revolution" as used in projection drawing means the rotation of an object into a specified position about an axis perpendicular to one of the principal planes. The axis is usually assumed to pass through or be tangent to the object, and the *direction* of rotation is specified as clockwise or counterclockwise on the view in which the axis is projected as a point. The *amount* of revolution may be specified either in degrees or so that one of the faces or edges comes to a certain position.

The *purpose* of revolution is to make it possible to draw an object in an oblique position, by first drawing it in a simpler position and then revolving

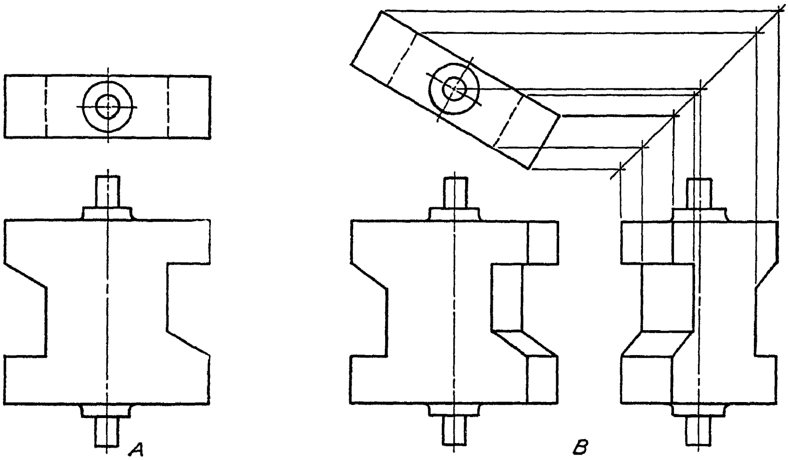


FIG. 330.—Revolution about a vertical axis.

it to the required position. Conversely, an object given in an oblique position may be brought into a simpler position by *counterrevolution.*

126. Rule for Revolution.—If an object is revolved about an axis perpendicular to a plane then (1) *its projection on that plane will change only in position, not in shape or size,* and (2) *the dimensions that are parallel to the axis on the other views will be unchanged. Illustration.*—If the object in Fig. 330 is revolved through 30° from the position *A* about a vertical axis, the top view will not change in shape but will take a position as shown in *B.* The vertical heights of all the points of the object remain unchanged in the revolution; thus the new front view can be found by projecting each point across from the original front view to meet a projecting line dropped from the corresponding point on the new top view. The side view is then drawn by the regular method of projection, as shown.

To avoid confusion it is well to number or letter the corresponding points on each view.

Similarly, if an object is revolved about a horizontal axis, perpendicular to the frontal plane, as in Fig. 331, the front view is unchanged in shape and is simply transferred by copying in the new position. The new top view can then be found by projecting across from the original top view and up from the new front view. The side view can be found as usual.

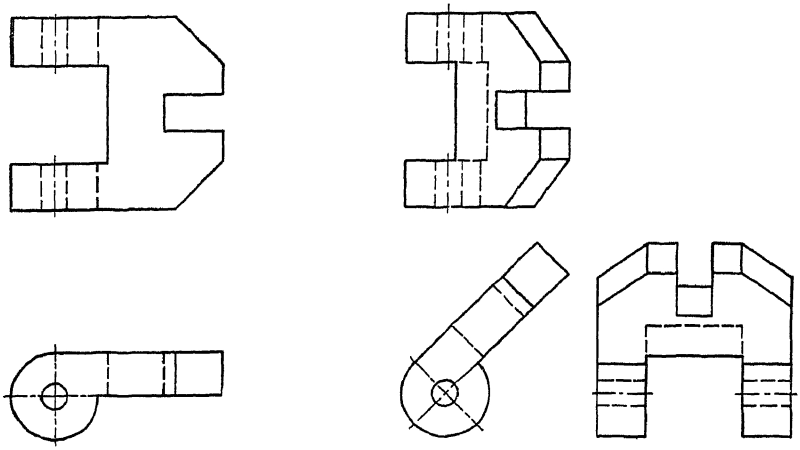


FIG. 331.—Revolution about a horizontal axis.

In a revolution forward or backward about an axis perpendicular to the profile plane the side view is the unchanged view. Thus the new front view is found by projecting across from the revolved side view and obtaining the widths from the original front view, Fig. 332.

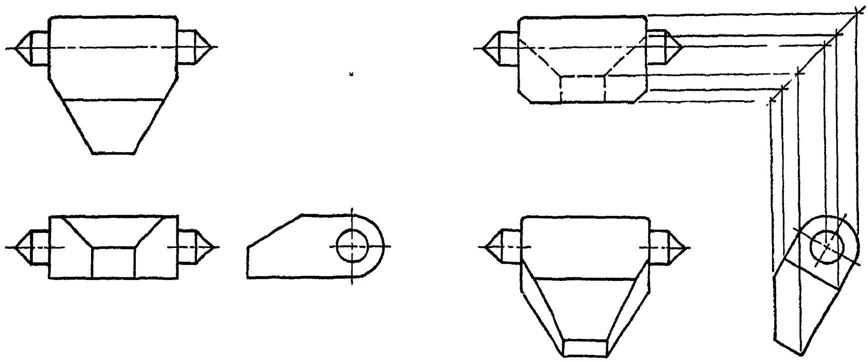


FIG. 332.—Revolution about an axis perpendicular to the profile plane.

127. Successive revolutions may be made under the same rules. Figure 333 shows a piece revolved first about a horizontal axis through 30° and then from this position about a vertical axis through 45°.

The only difference between the method of revolution and the method of auxiliary projection is that in the former the object is moved, while in the latter the observer is moved. The result is the same, as illustrated by Fig.

334. Although revolution has very little application in practical drafting, problems in it are an excellent aid to the student in understanding the theory of projection.

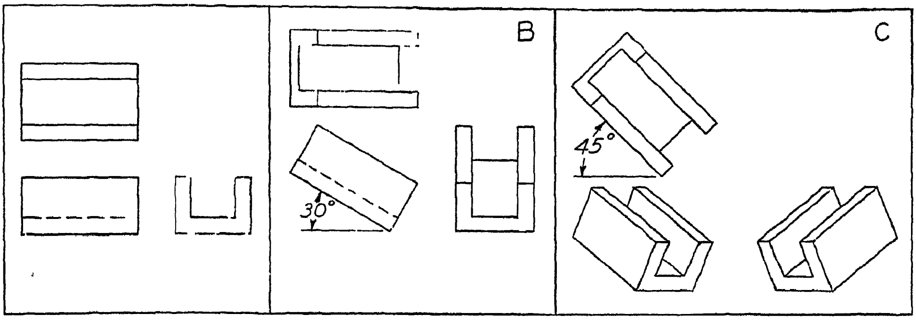


FIG. 333.—Successive revolutions.

128. The True Length of a Line.—A line oblique to the principal planes will not show in its true length in any of its principal views. If it is revolved into a position parallel to one of the principal planes its true length will be shown in that view. This may be easily understood by assuming the line to be an element of a cone as in Fig. 335. The slant lines of the front view of a cone show the true lengths of its elements. If the cone is imagined as revolving about its axis each element in turn will take a position parallel to the plane of projection. Thus if the line AB is assumed to be on a cone as in the figure, its true length is found by revolving the top view until the line is parallel to the frontal plane and projecting the revolved end down to meet the horizontal line corresponding to the front view of the base of the cone.

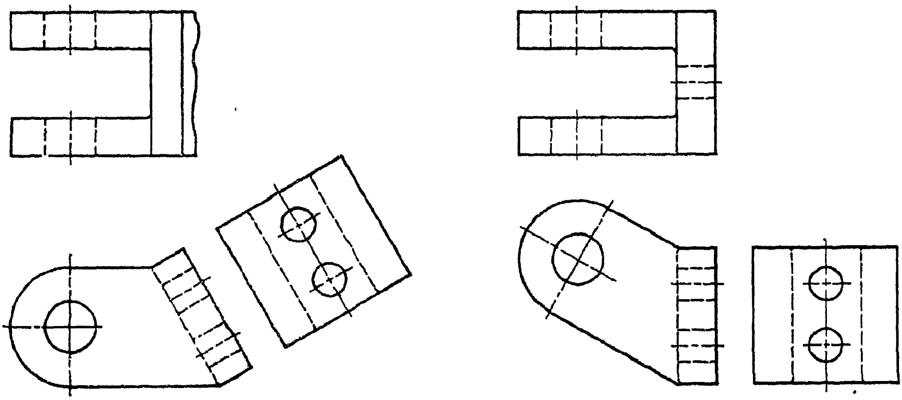


FIG. 334.—Comparison of auxiliary and revolution.

The true length of a line may also be found by making an auxiliary view of it on a plane parallel to it and perpendicular to a plane of projection, as illustrated in Fig. 336.

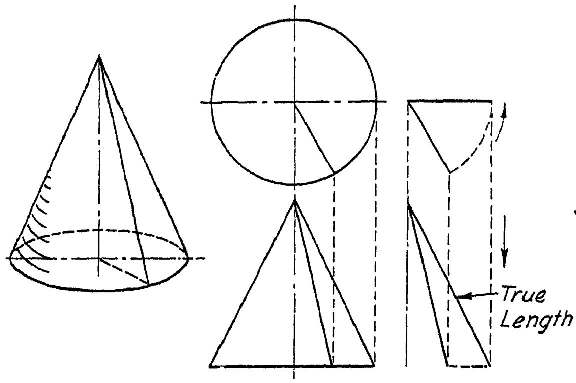


FIG. 335.—True length of a line, revolution method.

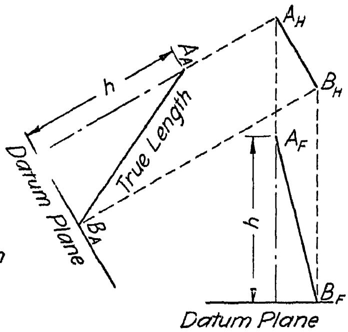


FIG. 336.—True length of a line, auxiliary view method.

PROBLEMS

Group I. Auxiliary views.
Group II. Double auxiliaries.
Group III. Revolution and counterrevolution.
Group IV. True lengths of lines.
Group V. Drawing from description.

Group I. Auxiliary Views. Probs. 1 to 21.

1, 2, 3, 4. Figs. 337 to 340. Draw views given and add auxiliary views on center lines or datum lines indicated.

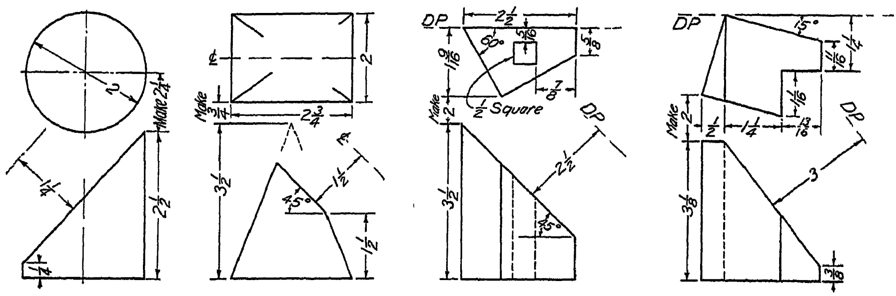


FIG. 337. FIG. 338. FIG. 339. FIG. 340.
FIGS. 337–340.—Auxiliary studies.

5. Fig. 341. Draw front view, partial top view and partial left auxiliary view.

6. Fig. 342. Draw partial front view, right side view, partial top view and partial front auxiliary view.

7. Fig. 343. Given front and right side views. Draw front view and right auxiliary view. Side view may be drawn if desired.

8. Fig. 344. Draw top view, partial front view and two auxiliary elevations.

9, 10. Figs. 345 and 346. Determine what views and part views will best describe the piece. Submit sketch before starting the drawing.

11. Fig. 347. Given front, left side and right side views. Draw front, right side and left auxiliary views.

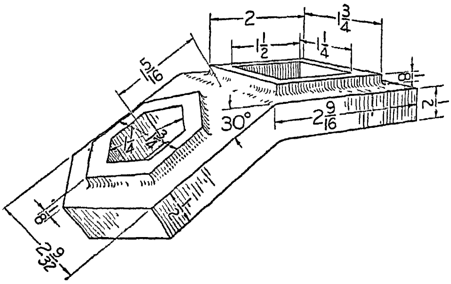


FIG. 341.—Holder.

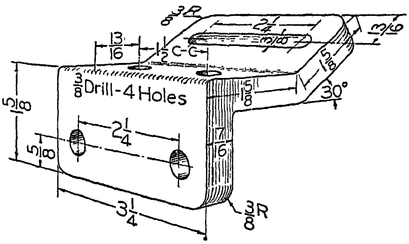


FIG. 342.—Slotted anchor.

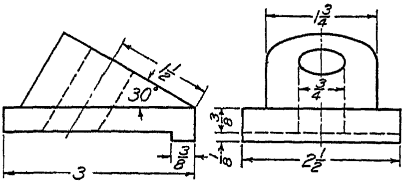


FIG. 343.—Bevel washer.

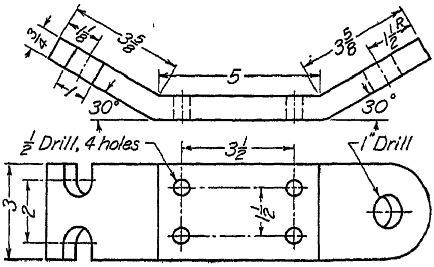


FIG. 344.—Connector strip.

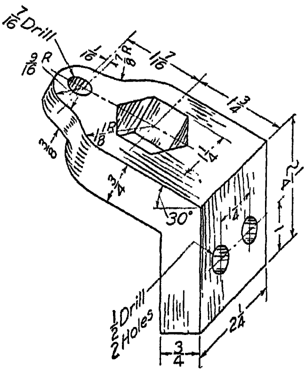


FIG. 345.—Jig angle.

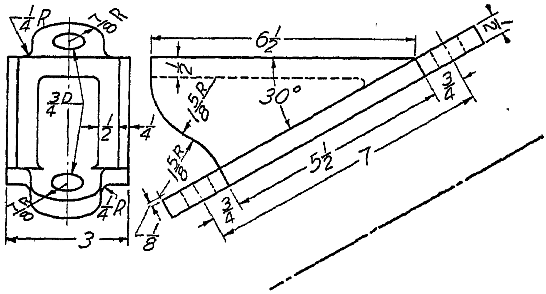


FIG. 346.—Angle bracket.

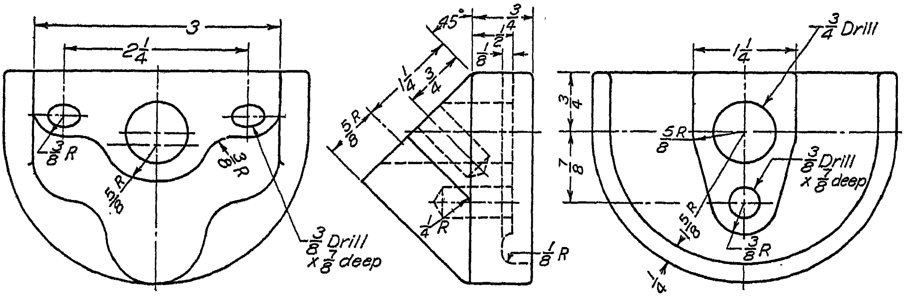


FIG. 347.—Circuit breaker stop.

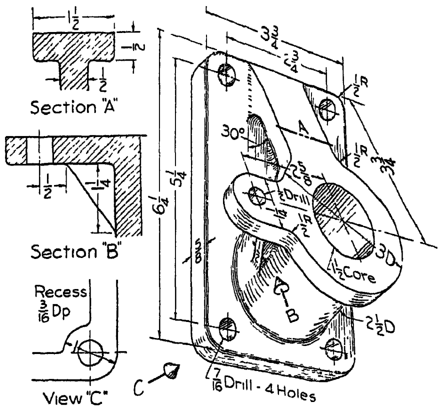


FIG. 348.—Angle shaft base.

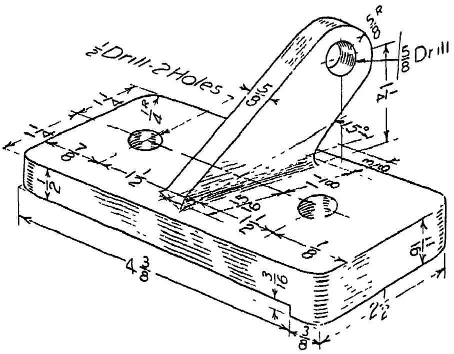


FIG. 349.—Anchor bracket.

12, 13. Figs. 348 and 349. Determine what views and part views will best describe the piece. Submit sketch before starting the drawing.

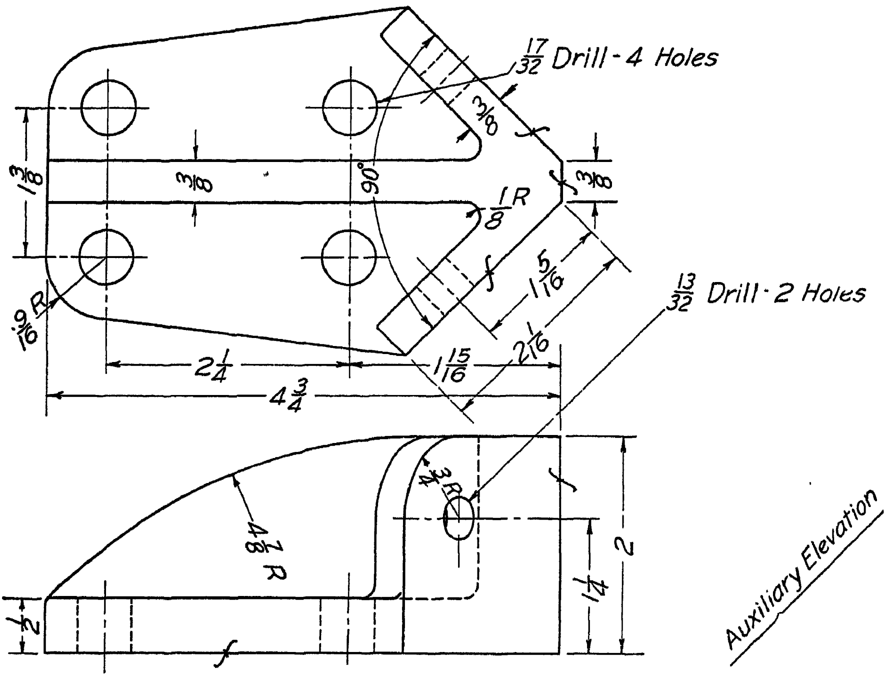


FIG. 350.—Push plate.

14. Fig. 350. Draw top view and partial auxiliary elevation. From these complete the front view.

15. Fig. 351. Draw front view, partial top view, partial right and left auxiliary views and partial left side view.

16, 17, 18, 19. Figs. 352 to 355. Determine what views and part views will best describe the piece. Submit sketch before starting the drawing.

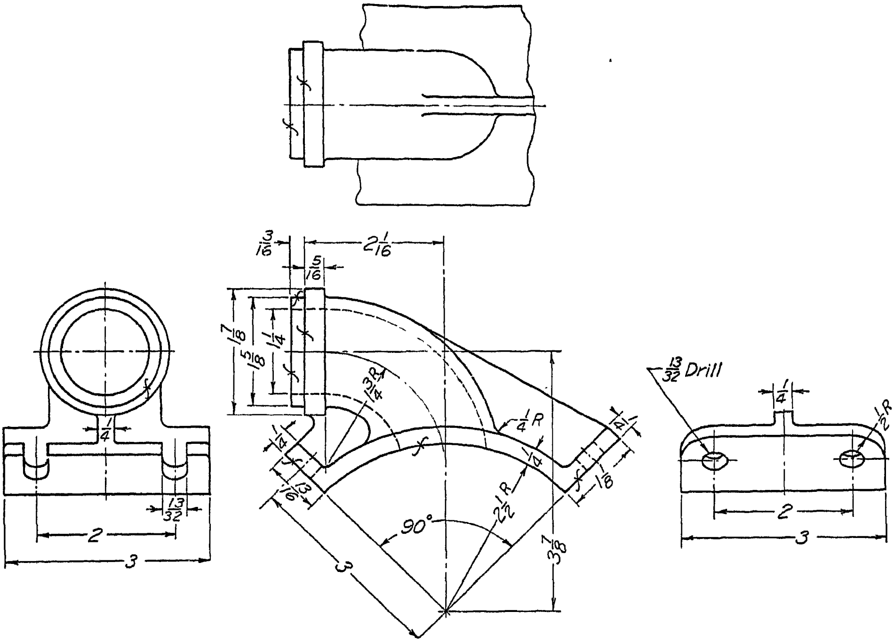


Fig. 351.—Diesel manifold.

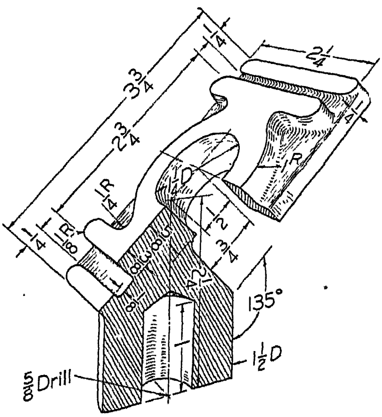


Fig. 352.—Catenary clip.

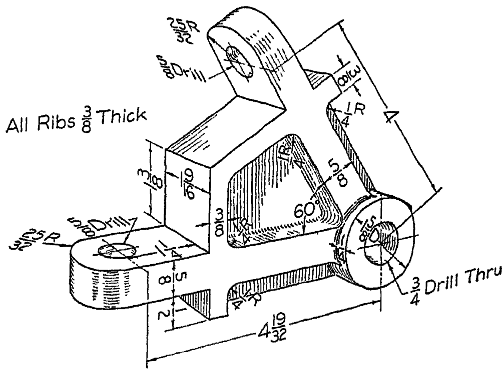
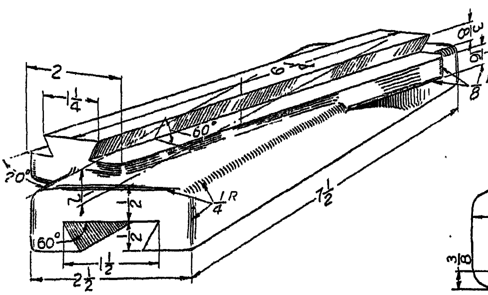
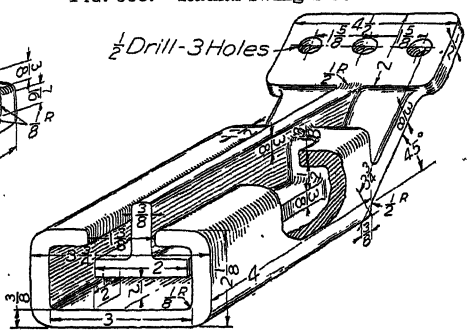


Fig. 353.—Radial swing block.





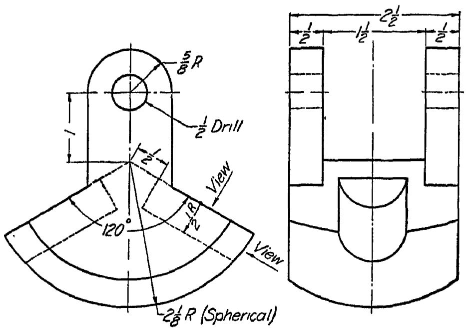


FIG. 356.—Universal base.

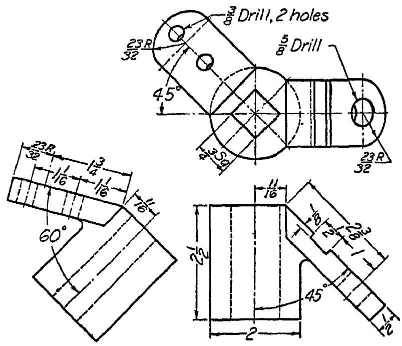


FIG. 357.—Bar strut anchor.

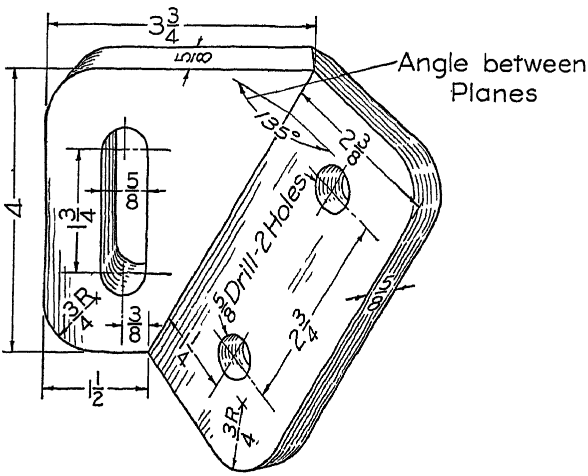


FIG. 358.—Adjustable clip.

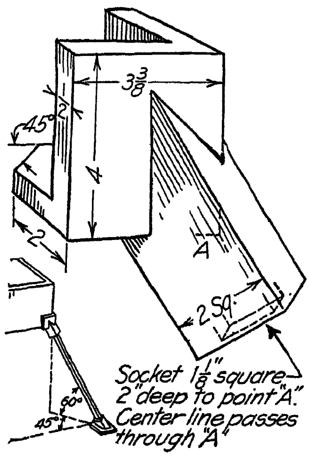


FIG. 359.—Corner bracket.

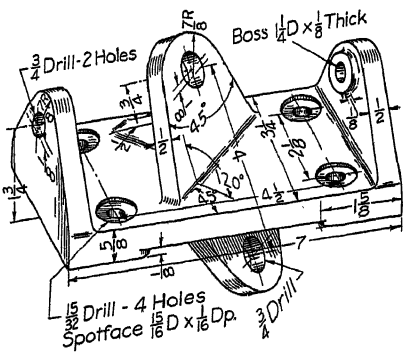


FIG. 360.—Transverse connection.

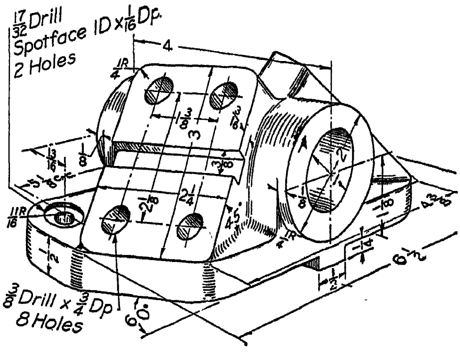


FIG. 361.—Chamfer tool base.

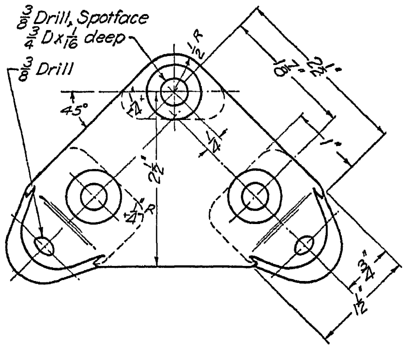


FIG. 362.—Cable anchor.

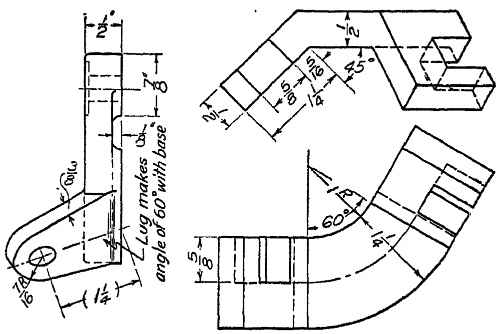


FIG. 363.—Segment clip.

20, 21. Figs. 356 and 357. Draw necessary views.

Group II. Double-auxiliary Views. Probs. 22 to 28.

22, 23. Figs. 358 and 359. Draw necessary views using double-auxiliary method.

24. Fig. 360. Draw top, front, left side (across from top), auxiliary elevation (part), and second auxiliary views (start top view in upper right-hand corner of 10″ × 14″ space).

25. Fig. 361. Draw top, front, auxiliary elevation (part) and second auxiliary (start top view in upper left corner of 10″ × 14″ space, with face *A* at the rear. The piece is symmetrical about main axis).

26, 27. Figs. 362 and 363. Draw views given by using double-auxiliary method.

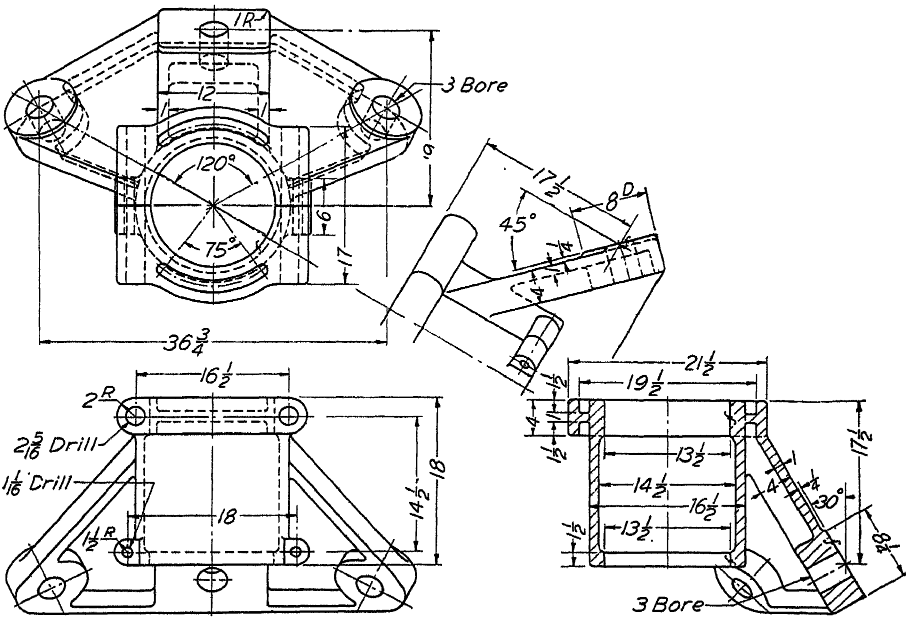


FIG. 364.—Crane mast-head collar and cap.

28. Fig. 364. Draw the layout of the views given and such additional auxiliary views as are necessary to complete the description of the piece. (8½″ × 13″ to one-eighth size.)

Group III. Revolution and Counterrevolution. Probs. 29 to 31.

29. Fig. 365. (1) Draw three views of one of the blocks A to K in the position shown. (2) Revolve from position (1) about an axis $\perp H$ through 15°. (3) Revolve from position (2) about an axis $\perp V$ through 45°. (4) Revolve from position (1) about an axis $\perp P$ forward through 30°. (5) Revolve from position (2) about an axis $\perp P$ forward

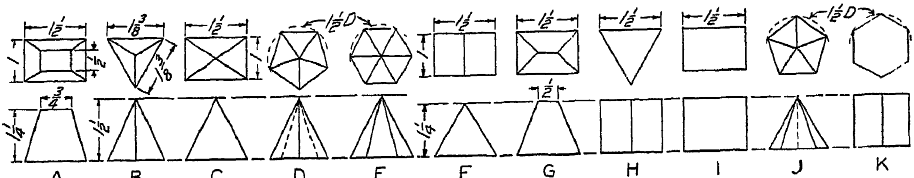


Fig. 365.—Problems in revolution.

through 30°. (6) Revolve from position (3) about an axis $\perp P$ forward through 30°. (4), (5) and (6) may be placed to advantage under (1), (2) and (3) so that the widths of front and top views mav be projected down directly.

30. Fig. 366. The triangle ABC is the base of a triangular pyramid, altitude $2\frac{1}{2}''$, whose apex is equidistant from A, B and C. Counterrevolve until the base is horizontal, and complete the figure.

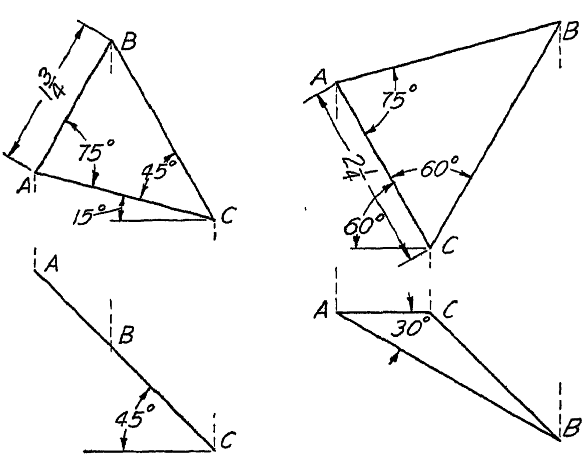


Fig. 366.—Counterrevolution.

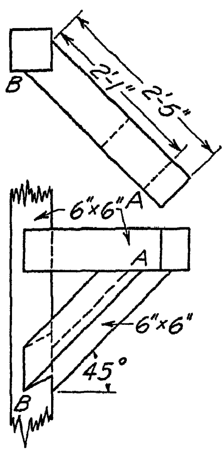


Fig. 367.—Timber brace.

31. Fig. 366. The triangle ABC is the base of a triangular pyramid, altitude $1\frac{1}{4}''$, whose faces make equal angles with the base. Counterrevolve in two operations, until the base is horizontal, and complete the figure.

Group IV. True lengths of Lines. Probs. 32 to 36.

32. Find the true length of the body diagonal of a $2\frac{1}{2}''$ cube.

33. Find the true length of an edge of one of the pyramids of Fig. 365.

34. Fig. 367. Find the true length of the line AB. Make a detail drawing of the brace.

35. Fig. 367. With the timbers in position shown draw the brace with the true length of AB, 3'-0".

36. Make a detail drawing of the brace of Prob. 35.

Group V. Drawing from Description. Probs. 37 to 46.

37. Draw three views of a triangular card each edge of which is $2\frac{3}{4}''$ long. One edge is perpendicular to P, and the card makes an angle of 30° with H.

38. Draw three views of a circular card of $2\frac{1}{2}''$ diameter, inclined 30° to H, and perpendicular to V. (Find eight points on the curve.)

39. Draw three views of a cylinder of $1\frac{1}{2}''$ diameter, $2''$ long, with hexagonal hole, $1''$ long diameter, through it. Axis of cylinder parallel to H and inclined 30° to V.

40. Draw top and front views of a hexagonal plinth whose faces are $1''$ square and two of which are parallel to H, pierced by a square prism, two faces of which are parallel to H, $3''$ long, base $\frac{7}{8}''$ square. The axes coincide, are parallel to H and make an angle of 30° with V. The middle point of the axis of the prism is at the center of the plinth.

41. Draw the two projections of a line $3''$ long making an angle of 30° with V and whose V projection makes 45° with a horizontal line, the line sloping downward and backward to the left.

42. Draw three views of a square pyramid whose faces are isosceles triangles $1\frac{3}{4}''$ base and $2\frac{1}{4}''$ altitude, lying with one face horizontal, the H projection of its axis at an angle of 30° with the horizontal.

43. Draw the top and front views of a right rectangular pyramid, base $1\frac{1}{8}'' \times 2''$, altitude $1\frac{7}{8}''$, long edges of base parallel to V. By two revolutions place the pyramid so that the short edges are parallel to H and make an angle of 60° with V while the apex is in the same horizontal plane as one of the short edges of the base.

44. Draw three views of a triangular pyramid formed of four equilateral triangles whose sides are $2\frac{1}{4}''$. The base makes an angle of 45° with H, and one of the edges of the base is perpendicular to V.

45. Draw top and front views of a rectangular prism, base $1'' \times 1\frac{3}{4}''$, whose body diagonal is $2\frac{1}{2}''$ long. Find projection of prism on an auxiliary plane perpendicular to the body diagonal.

46. Draw the top and front views of a cube whose body diagonal, $2\frac{1}{2}''$ long, is parallel to V. Make an auxiliary projection of the cube on a plane perpendicular to the body diagonal.

CHAPTER IX

SECTIONS AND CONVENTIONS

129. Sectional Views.—The two previous chapters have dealt with the method of describing the shape of an object by orthographic views, using dotted lines to indicate the invisible parts of it. If the object is very simple in its interior construction these hidden lines are not hard to read and understand. Often however, when the interior is complicated or when several different pieces are assembled in place, an attempt to show the construction on an exterior view would result in a confusing mass of dotted lines, annoying to draw and difficult if not impossible to read clearly. In such cases one (or more) of the views is made "in section." A *sectional view* or *section* is a conventional representation in which a part of an object or machine is imagined to be cut or broken away and removed so as to expose the interior. It must be understood clearly that in thus removing the nearer portion of the object in order to make the sectional view this portion is *not* assumed to be removed or omitted in making the other views.

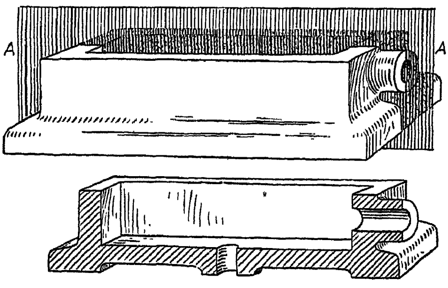


FIG. 368.—The cutting plane.

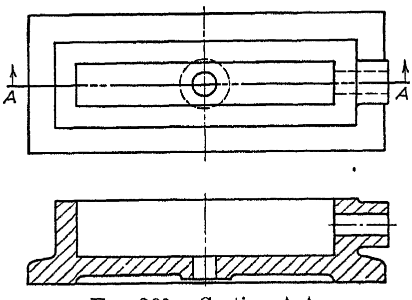


FIG. 369.—Section A-A.

When a drawing has more than one view in section, each sectional view should be considered separately without any reference to what has been cut away in other views.

130. Figure 368 shows the picture of a casting intersected by a cutting plane and the appearance of the casting as if it had actually been sawed through by the plane and the front part removed, exposing the interior. Figure 369 shows the drawing of the casting with the front view in section. The edge of the cutting plane is indicated on the top view by a line symbol (line 7 in the alphabet of lines, Fig. 46), with reference letters and arrows, the latter showing the direction in which the view is taken.

Wherever material has been cut by the section plane the cut surface is indicated by section lining, sometimes called "crosshatching," done with fine lines, generally at 45 degrees, spaced uniformly to give an even tint.

131. Five Principles in Sectioning.

1. The cutting plane need not be a continuous single plane but may be offset or changed in direction so as to show the construction to the best advantage. Fig. 370.

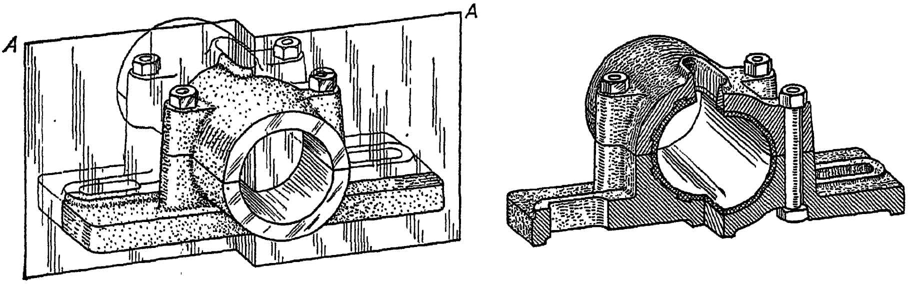


Fig. 370.—Picture of an offset cutting plane.

2. Shafts, bolts, nuts, rods, rivets, keys, and the like, whose axes occur in the plane of the section, are left in full and not sectioned. Fig. 371.
3. Invisible lines beyond the plane of the section should not be drawn unless necessary for the description of the piece.

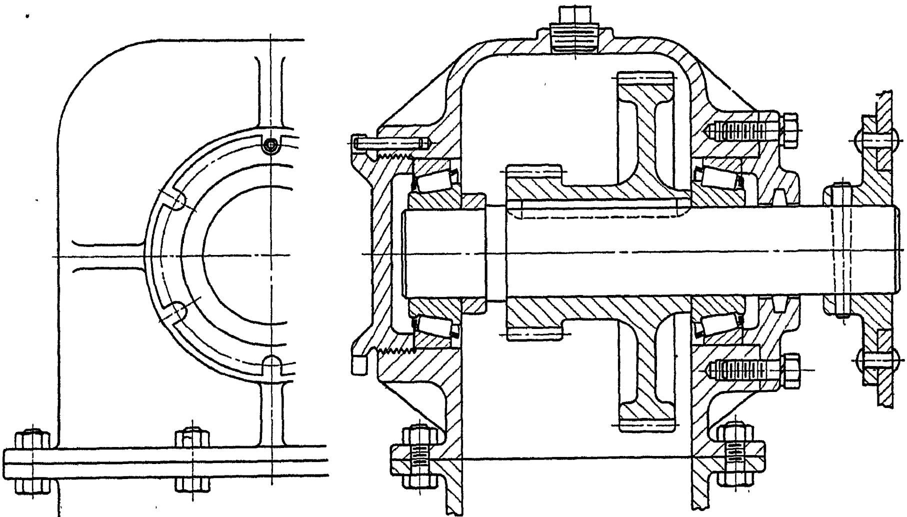


Fig. 371.—Section study.

4. Adjacent pieces are section-lined in opposite directions and are often brought out more clearly by varying the pitch of the section lines for each piece, using closer spacing for the smaller pieces. Fig. 380.
5. Section lining, either (1) for the same piece in different views, or (2) for the same piece in different parts of the same view should be identical in spacing and direction.

132. A full section is a sectional view in which the cutting plane cuts entirely across the object, showing the whole view in section. The cutting

plane is usually taken straight through on the main axis or center line, as in Fig. 369, but may be offset or changed in direction to go through some detail not on the axis, as in Fig. 370. Examples of full sections are shown in Figs. 642, 654, etc.

133. A half section is a view sometimes used with symmetrical objects, in which one half is drawn in section and the other half as a regular exterior view, Fig. 372. The cutting plane is imagined to extend halfway across,

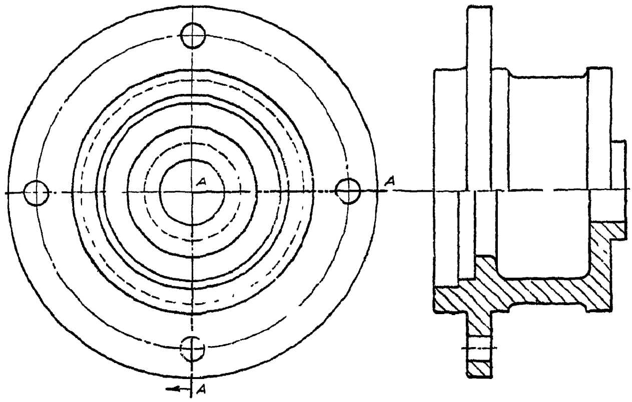


FIG. 372.—A half section.

stopping at the axis or center line. A half section has the advantage of showing both the exterior and the interior on one view but has the disadvantage that inside diameters cannot be dimensioned well. Hidden lines are not drawn on either side except where necessary to describe the construction. Examples of half sections are given in Figs. 640 and 652.

134. A broken-out section is a partial section used on an exterior view to show some interior detail without drawing a complete full or half section.

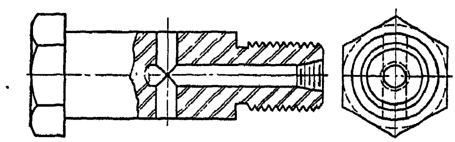


FIG. 373.—A broken-out section.

The object is imagined to be sawed by a cutting plane through the portion to be shown, and the part in front broken out, leaving an irregular break line, which, along with part of the contour of the object will bound the broken-out section. Figures 373 and 676 show examples.

135. A revolved section, made directly on an exterior view, provides a very convenient and useful method of showing the shape of the cross section of some detail of construction, such as a rib or the arm of a wheel. The cutting plane is passed perpendicular to the center line or axis of the part to be sectioned and the resulting section revolved or turned up in place,

Fig. 374. These are used primarily for shape description rather than size description. When lines of the outline interfere with the section, as is sometimes the case, the view may be broken away to make a clear space for the sectional view. Figures 390, 610 and 679 contain some examples of revolved sections, or, as they are sometimes called, "interpolated sections."

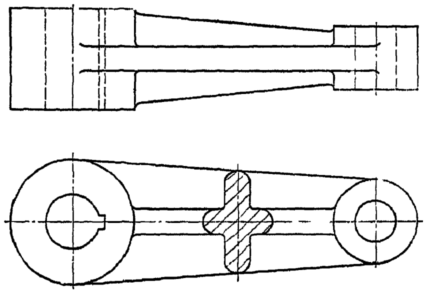


FIG. 374.—A revolved section.

136. Detail sections, or **removed sections,** are for the same purpose as revolved sections but, instead of being drawn on the view, they are set off, or shifted, to some adjacent place on the paper, so that dimensions may be added, Fig. 375. The cutting plane, with reference letters, should always be indicated. When the shape of a piece is not uniform, several of these cross sections may be required, Fig. 376. It is often of advantage to draw them to larger scale than that of the main drawing, in order to show dimensions more clearly. Detail sections are sometimes called "separate sections," "shifted sections," or "sliced sections." Examples of removed sections occur in Fig. 669.

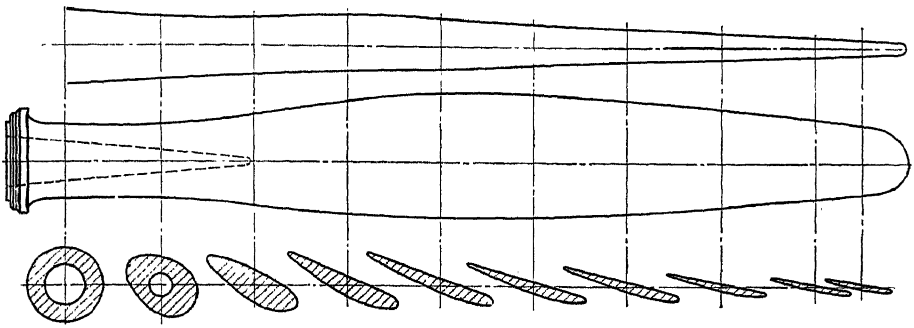


FIG. 375.—Removed sections.

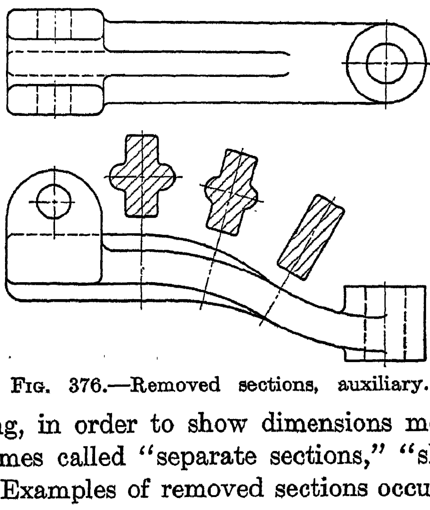


FIG. 376.—Removed sections, auxiliary.

137. A phantom section is an exterior view with the interior construction brought out by dotted crosshatching, Fig. 377. It is rarely used, its only advantage being that in those cases where a broken-out section would cut

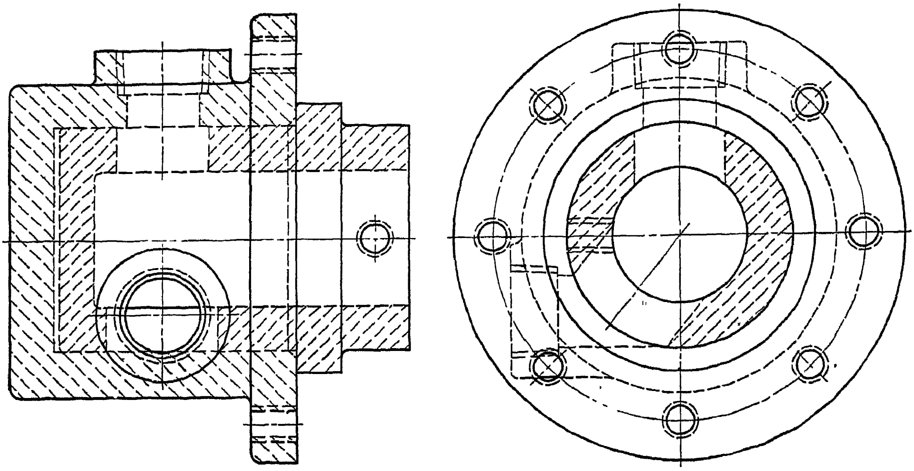


FIG. 377.—A phantom section.

away some detail on the outside, the phantom section enables this detail to be preserved. The term "phantom" is also used to indicate an absent part, dotted in to show the relative position of a piece, as in Figs. 641 and 647.

138. An auxiliary section is a sectional view made on an auxiliary plane, that is, a plane perpendicular to one of the principal planes and inclined to the other two. Its construction conforms to all the principles of auxiliary views as explained in the previous chapter; thus there may be an auxiliary sectional elevation, a right or left auxiliary section and a front or rear auxiliary section. Similarly, half sections, broken-out sections, revolved sections and removed sections may be used on auxiliary views. Figure 378 is an example of a right auxiliary section.

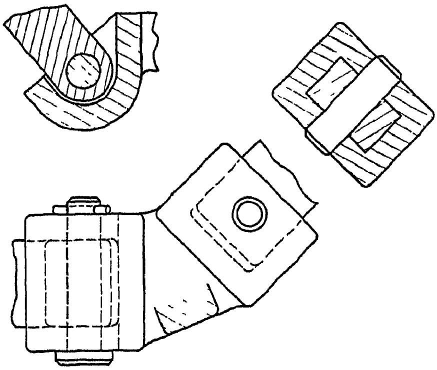


FIG. 378.—A right auxiliary section.

139. Section lining, or crosshatching, is done with very fine sharp lines spaced entirely by eye, except when some form of mechanical section liner is used. The pitch, or distance between lines, is governed by the size of the surface. For ordinary working drawings it will not be much less than 1/16 inch and rarely over 1/8 inch. Very small pieces will have closer spacing. Care should be exercised in setting the pitch by the first two or three lines

and one should glance back at the first lines often in order that the pitch may not gradually increase or decrease. Nothing mars the appearance of a drawing more than poor section lining.

Shafts, bolts, nuts, screws, keys, pins, rivets, balls, rollers, etc., whose axes lie in the cutting plane, have no interior parts to be shown and consequently are left in full on assembly sections, as if they had been removed when the section was cut and afterward laid back in place, Fig. 371.

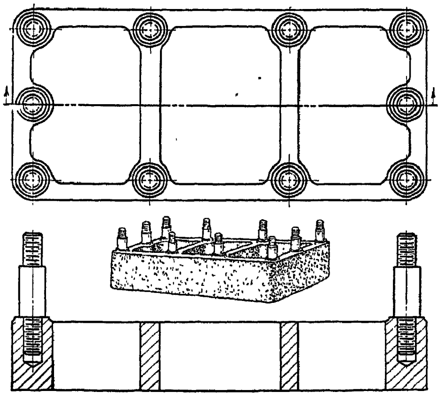


FIG. 379.—Omission of detail.

In general the rules of projection are followed in making sectional views, but confusion in reading a complicated piece may occur if all the detail behind the cutting plane is drawn. To ensure clearness such detail as is not required in explaining the construction should be omitted, as in Fig. 379.

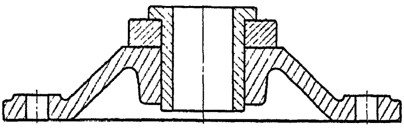


FIG. 380.—Adjacent parts.

Two adjacent pieces in an assembly section are sectioned in opposite directions. If three pieces adjoin, one of them must be sectioned at other than 45 degrees. If a part is so shaped that 45-degree sectioning runs parallel or nearly so to one of its outlines, another direction should be chosen, Fig. 380.

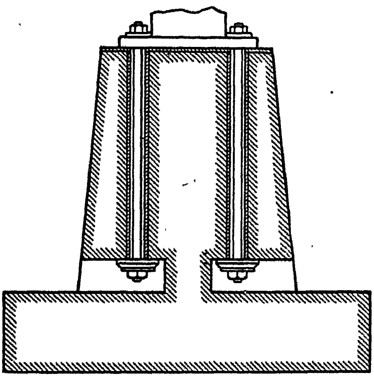


FIG. 381.—Outline sectioning.

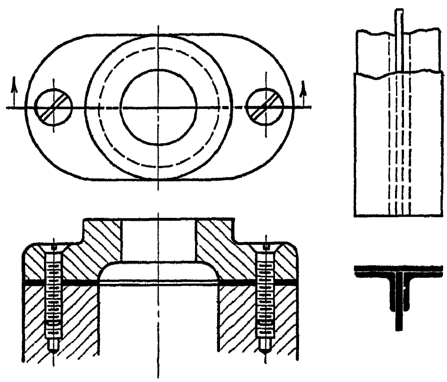


FIG. 382.—Thin material in section.

Large surfaces are sometimes sectioned only around the edge, as illustrated by Fig. 381.

Very thin sections, as of gaskets, sheet metal, or structural steel shapes to small scale, may be shown in solid black, with white spaces between the parts where thin pieces are adjacent, Fig. 382.

140. Conventional Sections.—Sometimes added clearness may be gained by violating the strict rules of projection. This is often done in making sectional views, as in a section of a pulley. Compare Figs. 645 and 642, one of a three-arm pulley, the other of a pulley with solid web. The true pro-

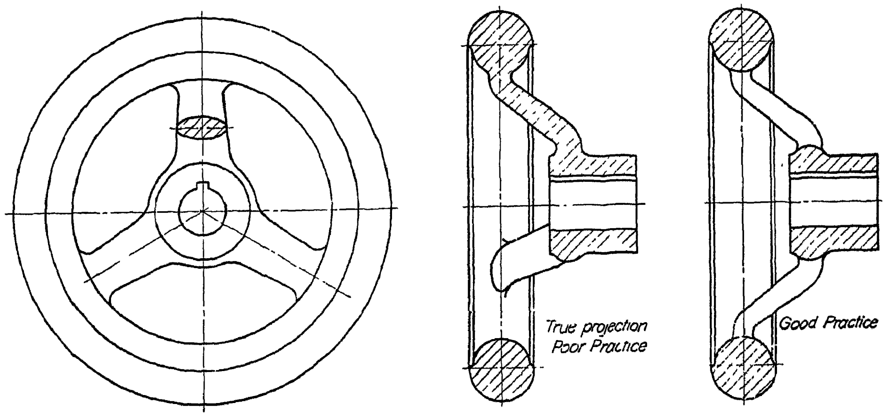


FIG. 383.—Aligned section.

jection of a section of the handwheel, Fig. 383, is unsymmetrical and misleading, therefore not good practical drawing. The preferred form is shown in the second view, where the foreshortened arm is drawn as if revolved, or aligned, and neither arm section-lined.

141. Ribs in Section.—When the cutting plane passes longitudinally through the center of a rib or web a true sectional view with the rib cross-

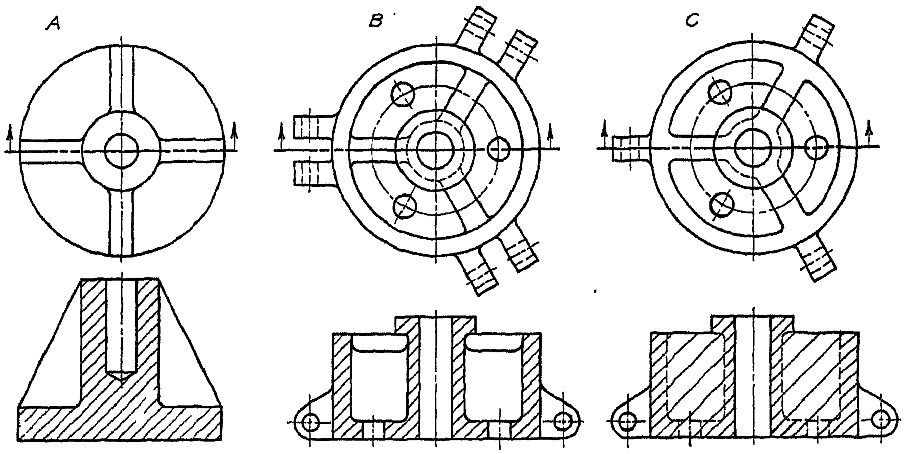


FIG. 384.—Ribs in section.

hatched gives a heavy and misleading effect. The standard conventional method of drawing such a view is to omit the section lines from the rib, as if the cutting plane were just in front of it, Fig. 384 *A*. At *B* an *aligned section* is shown. The cutting plane goes through the rib on the left side

and through one of the holes in the base on the right side. The parts are aligned or revolved to the cutting plane, then projected to the front view to make a symmetrical section. The prominent fillets in the sectional view show that the ribs run to the bottom of the piece and are not small spokes at the top. The lugs are, of course, not sectioned, because the cutting plane does not cut through them. The object at *C* is similar to *B* except that the ribs extend to the top of the piece. Here alternate crosshatching is used to identify the ribs in the sectional view. Half the crosshatch lines are carried through the rib, and the line of intersection between the solid body and the rib is dotted. Section lines are omitted on the lugs for the same reason as given for *A*. Alternate crosshatching is rarely necessary and should be used only when the other conventional method is inadequate or ambiguous.

142. Drilled flanges in section should show the holes at their true distances from the center whether or not their axes come in the plane of the

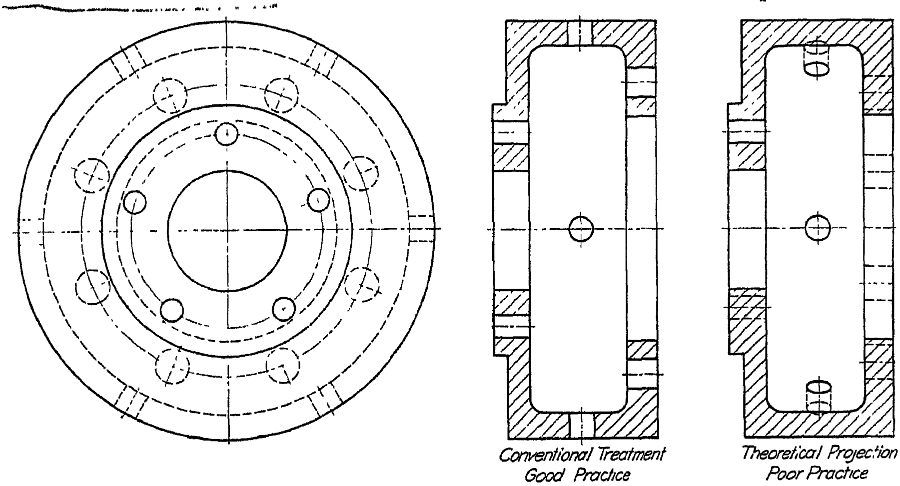


FIG. 385.—Conventional representation of drilling.

section. In Fig. 385 the true projection of the holes is misleading. It is better practice to show them at their true radial distance, as if they were swung around into the plane of the section. This applies also to flanges in full views. Pipe fitters use the terms "one up" and "two up" to indicate whether a flange on a horizontal run has one or two holes at the top.

143. Code for Materials in Section.—Symbolical section lining is not commonly used on ordinary working drawings, but sometimes in an assembly section it is desired to show a distinction between materials, and a recognized standard code is of obvious advantage. The American Standards Association's symbols for indicating different materials will be found in the Appendix, page 602. Code section lining is used only as an aid in reading the drawing and is not to be taken as the official specification of the materials. Exact specifications of the material for each piece are always given on the detail drawing.

A common use of symbolic sectioning is in representing bearing or lining metal. It is a universal practice to indicate such metal by the conventional symbol of crossed lines. The quickest way to make this symbol is to section over both the lining metal and the adjacent cast iron at once, then to cross

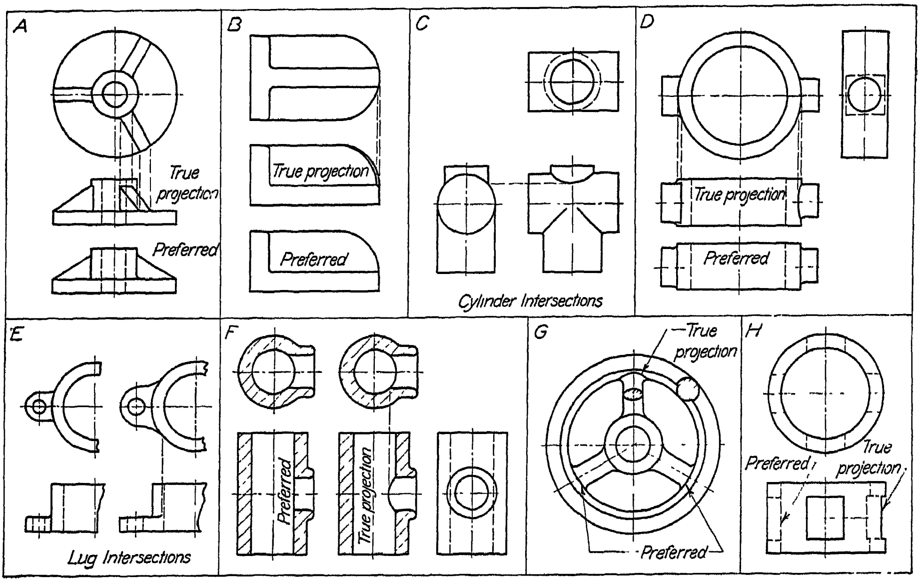


Fig. 386.—Conventional intersections.

the lining metal in the other direction; but a better effect is gained by making it separately with finer pitch.

144. Conventional Practices.—There are violations of the rules of true projection in full views as well as in sectional views that are recognized as good practice because they add to the clearness of the drawing. For example, if a front view shows a hexagonal bolthead "across corners" the theo-

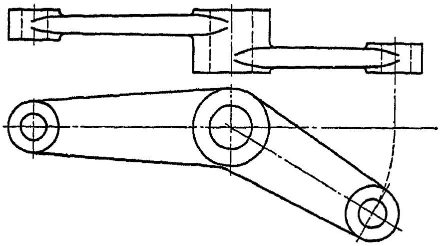


Fig. 387.—Aligned view.

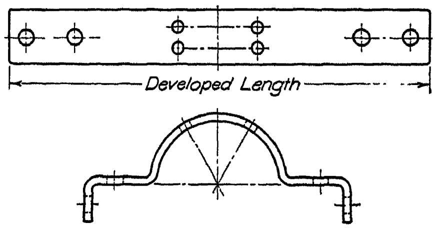


Fig. 388.—Developed view.

retical projection of the side view would be "across flats," but in a working drawing when boltheads occur they should be drawn across corners in both views, to show the space needed.

Some typical examples, in which true lines of intersection are of no value as aids in reading the drawing and are therefore ignored, are shown in Fig. 386.

Pieces which have parts at an angle with each other, as the lever of Fig. 387, may be shown straightened out, or aligned, in one view. Similarly, bent pieces of the type of Fig. 388 should have one view made as a developed view of the *blank* to be punched and formed. Extra metal must be allowed for bends. See paragraph 397.

Lugs or parts cast on for holding purposes and to be machined off are shown in phantom in dashed lines. If in section, the section lines are dotted.

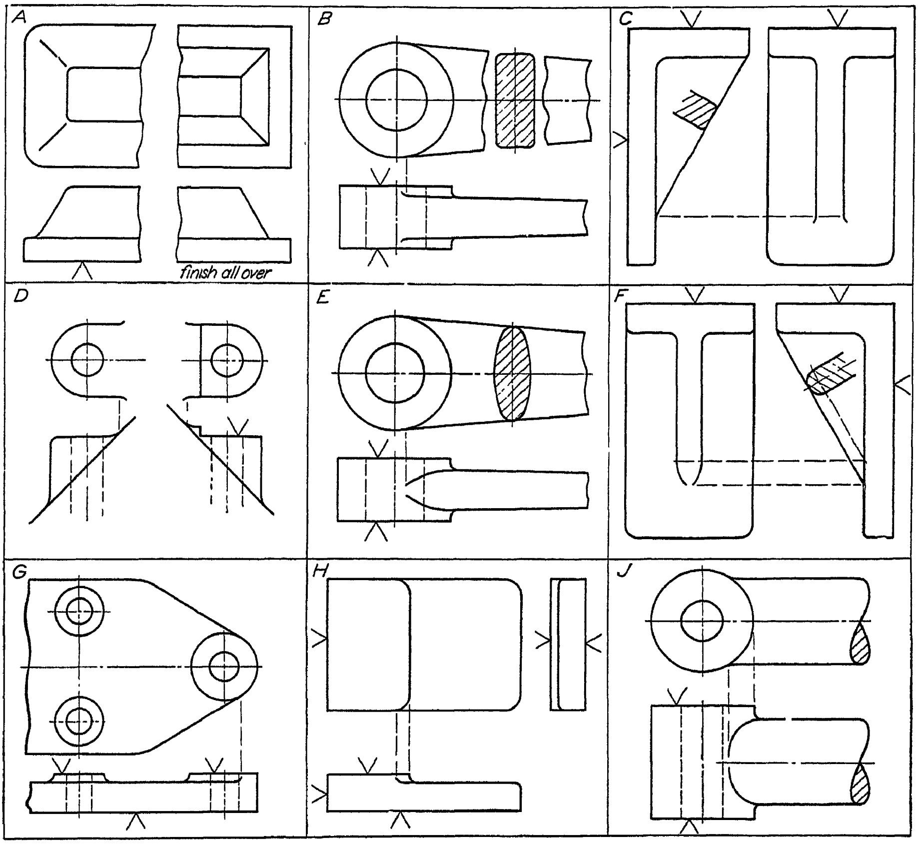


FIG. 389.—Conventional fillets, rounds and runouts.

Dashed lines are also used for indicating the limiting positions of moving parts and for showing adjacent parts that aid in locating the position or use of the piece.

145. Fillets and Rounds.—In designing a casting, sharp internal angles must never be left, because of the liability to fracture at those points. The radius of the fillet depends on the thickness of the metal and other design conditions. When not dimensioned it is left to the patternmaker. External angles may be rounded for appearance or comfort, with radii ranging from enough merely to remove the sharp edges, to an amount nearly equal to the

thickness of the piece. An edge made by the intersection of two unfinished surfaces of a casting should always be "broken" by a very small round. A sharp corner on a drawing thus indicates that one or both of the intersecting surfaces are finished. These minute rounds as well as other small fillets and "runouts" are best put in freehand both in pencil and ink.

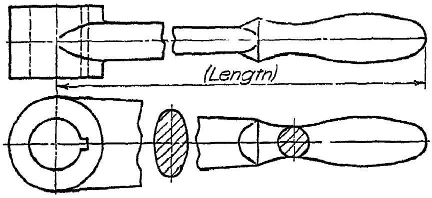


FIG. 390.—Broken view, with revolved sections.

Runouts, or die-outs as they are sometimes called, are conventional indications of filleted intersections where theoretically there would be no line, as there is no abrupt change in direction. Figure 389 shows some conventional representations of fillets and rounds, with runouts of arms and brackets intersecting other surfaces.

146. Conventional Breaks.—In making a detail of a long bar or piece with uniform shape of cross section, there is evidently no necessity for drawing its whole length. It may be shown to a larger and thus better scale by

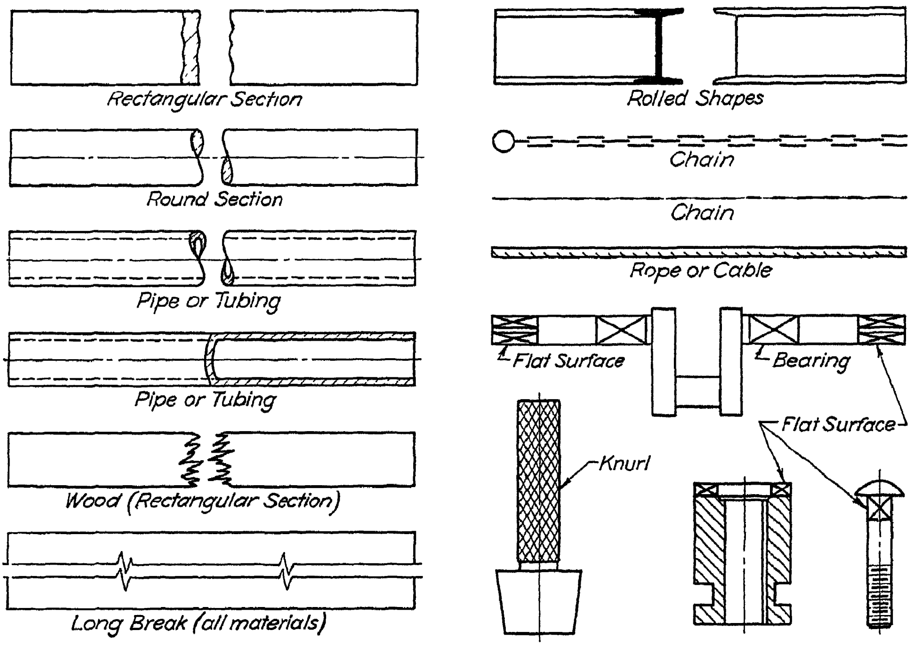


FIG. 391.—Conventional breaks and other symbols.

breaking out a piece, moving the ends together and giving the true length by a dimension as in Fig. 390. The shape of the cross section is indicated either by a revolved section, or oftener by a semipictorial break line, as in Fig. 391. This figure shows also some other conventional symbols.

147. Half Views.—When space is very limited it is allowable practice to make the top or the side view of a symmetrical piece as a half view. If the front is an exterior view, the *front* half of the top or the side view would be used, as in Fig. 392, but if the front view is a sectional view the *rear* half would be used, as in Fig. 393. Figure 394 shows another space-saving combination of a half view with a half section. Examples of half views occur in Figs. 609, 640 and 646.

148. Conventional Symbols.—Draftsmen use conventional representation for indicating many details, such as screw threads, springs, pipe fittings, electrical apparatus, etc. These have been standardized by the ASA, whose code for materials in section has already been referred to in paragraph 143.

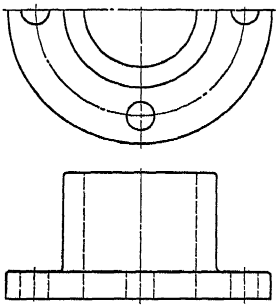


FIG. 392.—Half top view.

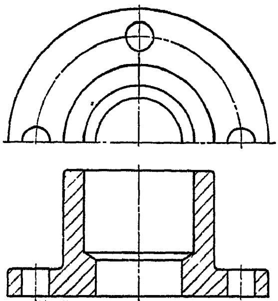


FIG. 393.—Half top view and full section.

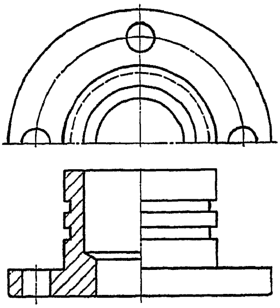


FIG. 394.—Half top view and half section.

The symbol of two crossed diagonals is used for two distinct purposes: first, to indicate on a shaft the position of finish for a bearing, and second, to indicate that a certain surface (usually parallel to the picture plane) is flat, but these two uses are not apt to be confused, Fig. 391.

Because of constant recurrence the representation of screw threads is one of the most important items under conventional symbols. Up to the time of their official standardization by the ASA there were a dozen different thread symbols in use. Now, one regular symbol and one simplified one are adopted for American drawings, and both are understood internationally. These symbols for indicating threads on bolts, screws and tapped holes are given in Chap. XII. This chapter also shows the conventional representation of helical springs. The conventional methods of representing pipe and fittings are given in Chap. XIII. Welding symbols are shown in Chap. XV.

The conventional symbols mentioned in the last paragraph are used principally on machine drawings. Architectural drawing, on account of the small scales employed, uses many conventional symbols, and topographic drawing is made up entirely of symbols. It is suggested that the reader consult the Index of this book to find the symbol for some item desired.

PROBLEMS

149. Selections from the following problems may be used for shape description only, or as working drawings by adding dimensions.

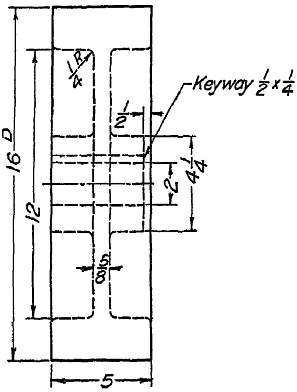


Fig. 395.—Pulley.

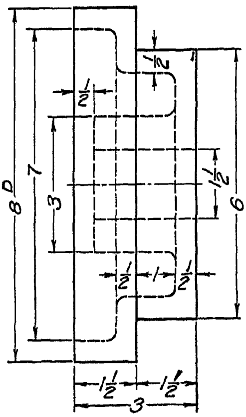


Fig. 396.—Step pulley.

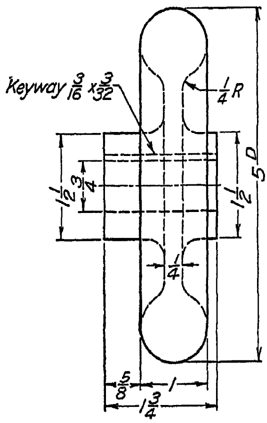


Fig. 397 —Handwheel.

1, 2, 3. Figs. 395 to 397. Draw a full front view, and a side view in section. Scale to suit.

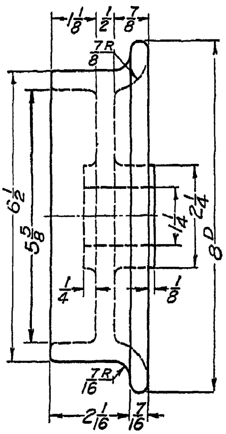


Fig. 398.—Flanged wheel.

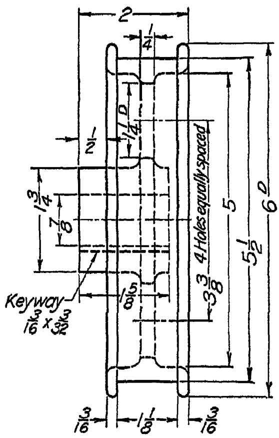


Fig. 399.—Flanged pulley.

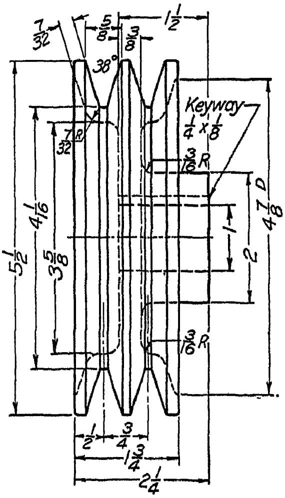


Fig. 400.—Vee belt pulley.

4, 5, 6. Figs. 398 to 400. Draw a full front view and a side view in section.

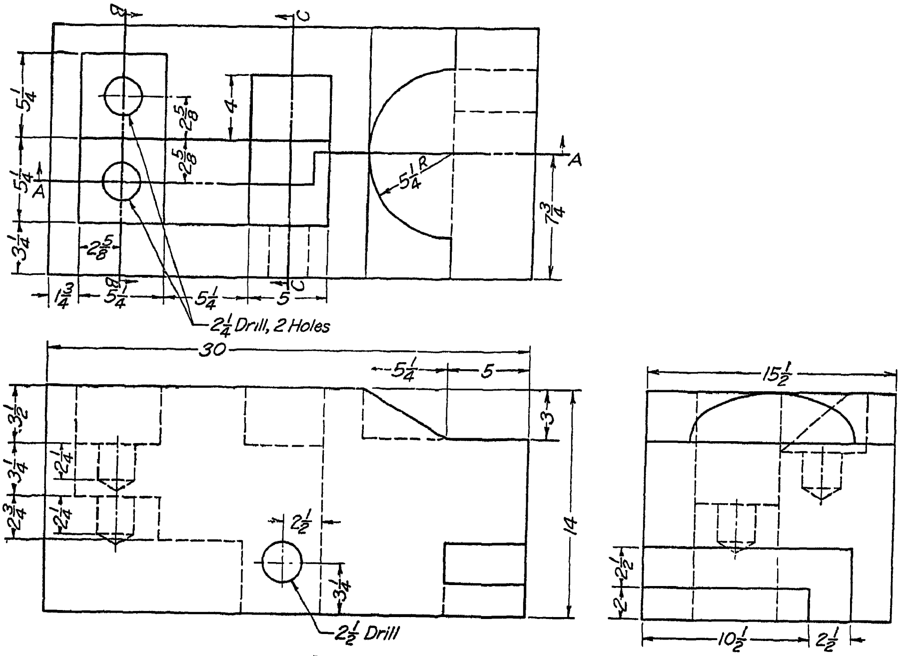


FIG. 404.—Section study.

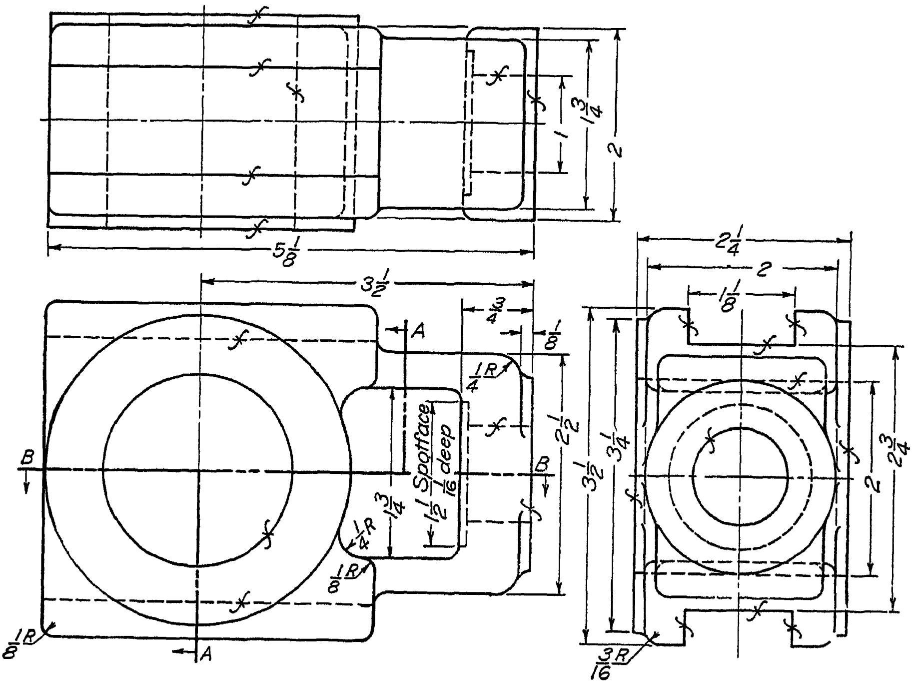


FIG. 405.—Crosshead.

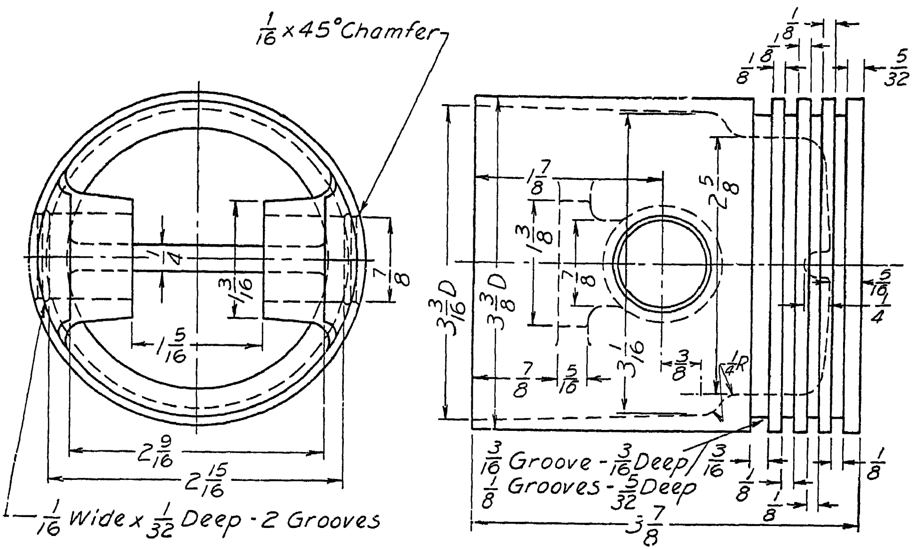


FIG. 406.—Gasoline engine piston.

10. Fig. 404. Draw top view and make front and two side views on cutting planes indicated.

11. Fig. 405. Draw three views, making side view as a section on *A-A*.

12. Fig. 405. Draw three views, making top view as a section on *B-B*.

13. Fig. 406. Draw two views of piston, the right half of end view to be a section on the center line of piston pin. Lower half of front view to be in section. (6″ × 10″ space).

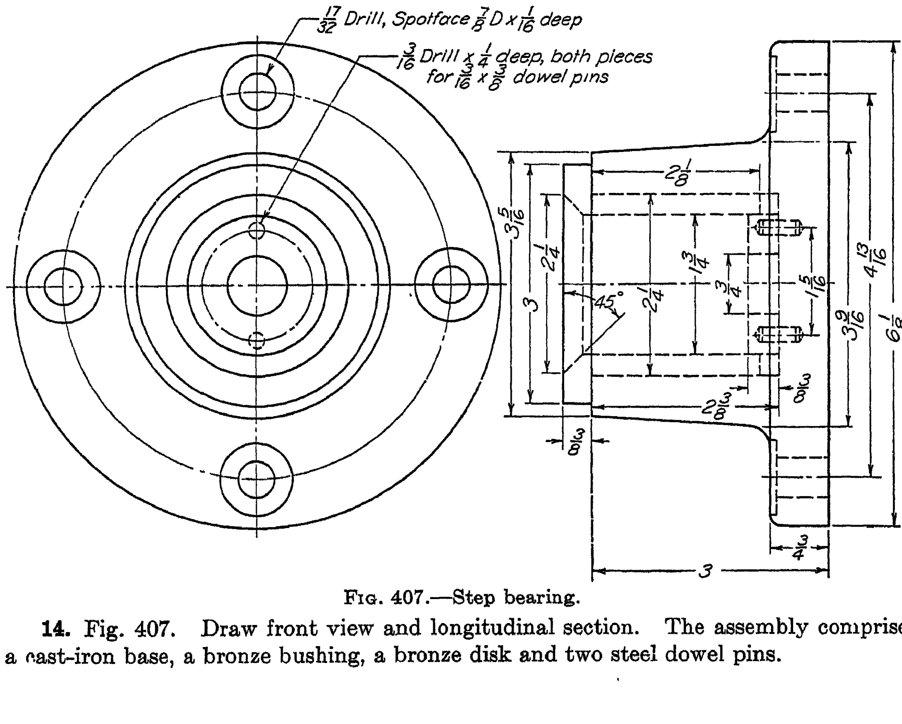


FIG. 407.—Step bearing.

14. Fig. 407. Draw front view and longitudinal section. The assembly comprises a cast-iron base, a bronze bushing, a bronze disk and two steel dowel pins.

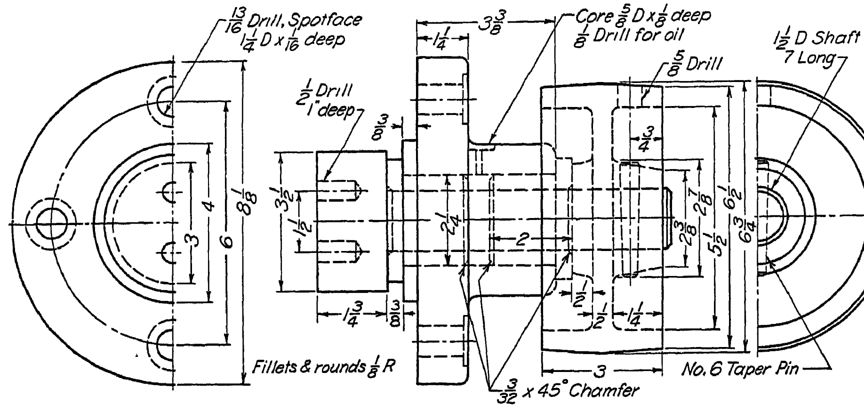


FIG. 408.—Pulley bracket assembly.

15. Fig. 408. Draw two half end views and longitudinal section. The assembly consists of cast-iron body, two bronze bushings, steel shaft, cast-iron pulley and steel taper pin. Use the conventional symbols for crosshatching the various materials, as given in the Appendix. Adjacent parts should be crosshatched in opposite directions, as illustrated in Fig. 380, in order to indicate the different pieces.

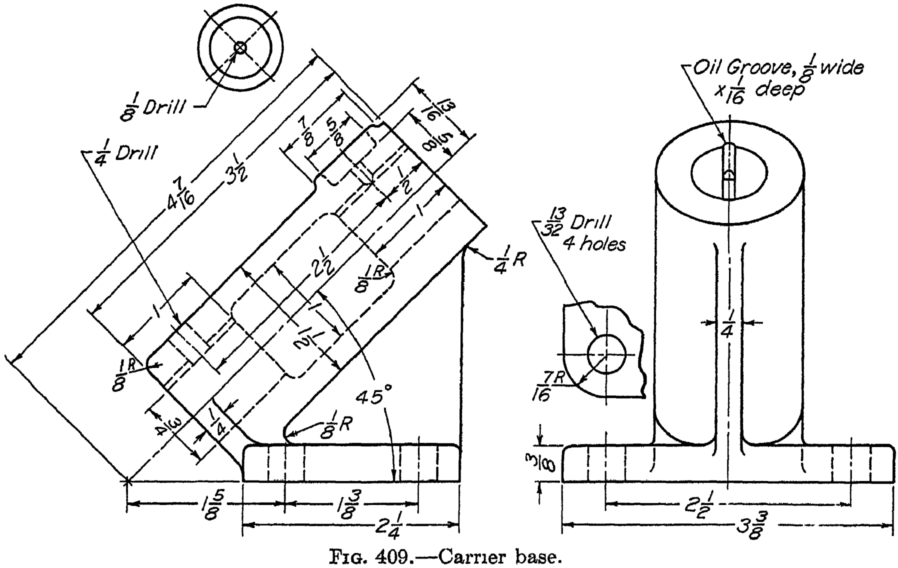


FIG. 409.—Carrier base.

16. Fig. 409. Draw the views given, and add sectional views as follows: (*a*) auxiliary section taken on a plane perpendicular to main axis and through ⅛″ oil hole; (*b*) auxiliary section as (*a*) but through center portion to show wall thickness; (*c*) auxiliary section as (*a*) but through ¼″ drilled hole in lower portion. The base should not be shown in the sectional views, but supporting ¼″ rib should be indicated as to position and thickness.

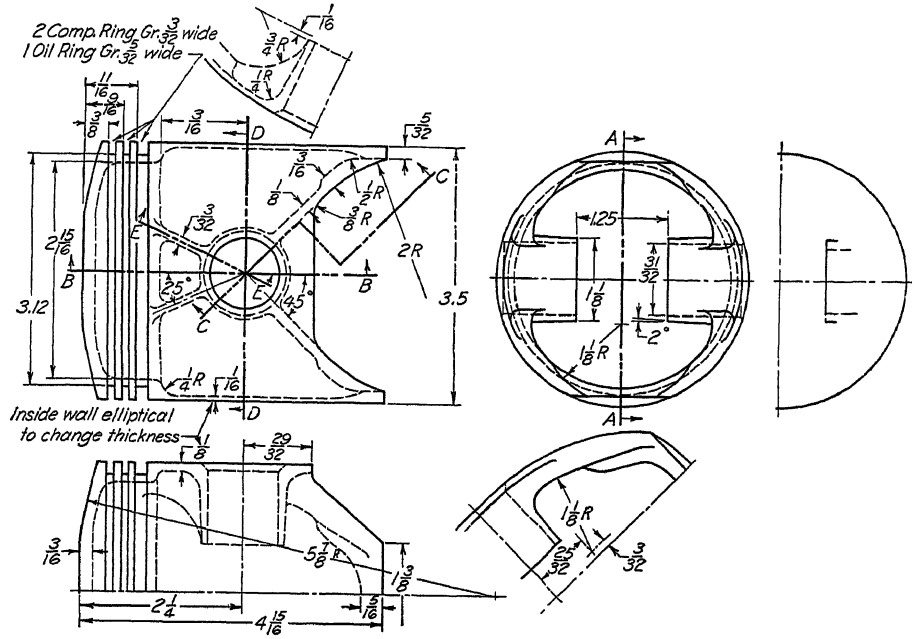


FIG. 410.—Automobile piston (Chevrolet).

17. Fig. 410. Draw the automotive piston, making sectional views as indicated. Section *D-D* is to be a half view to the right of the full end view. Note that section *D-D* will show the elliptical inside wall, and that in section *C-C* the outline of the view is a portion of an ellipse.

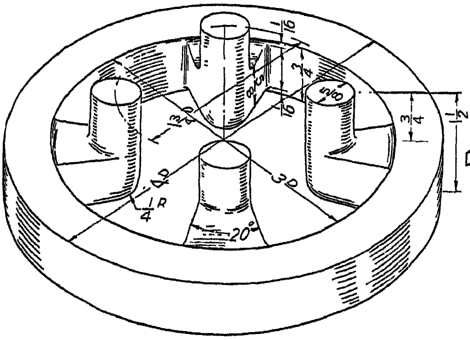


FIG. 411.—Selector ring.

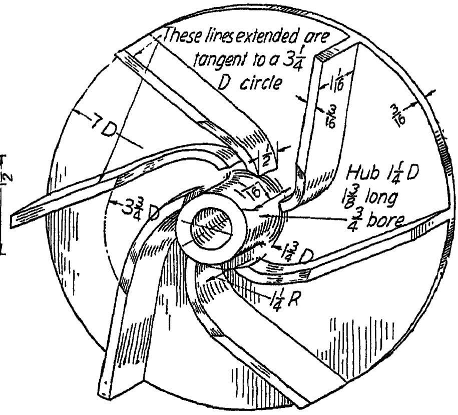


FIG. 412.—Impeller.

18. Fig. 411. Draw top view, and front view in conventional section.
19. Fig. 412. Draw front view, and side view in conventional section.

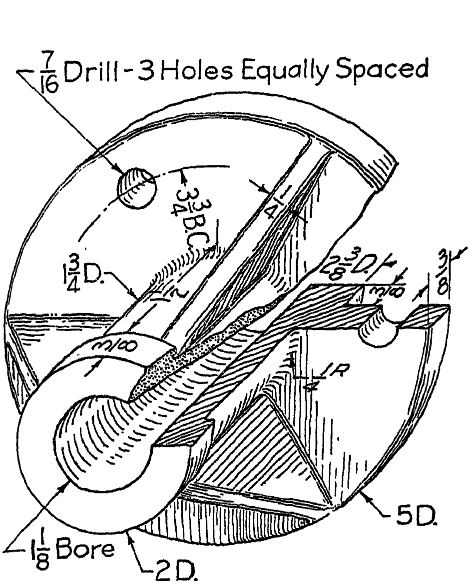


FIG. 413.—Support.

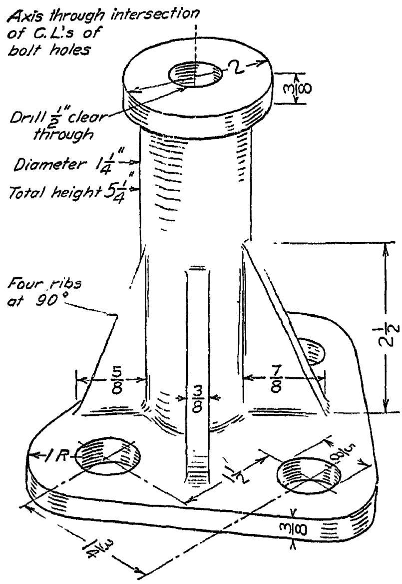


FIG. 414.—Stem support.

20. Fig. 413. Draw front view, and side view in conventional section.

21. Fig. 414. Select views which will best describe the piece. Submit sketch before drawing.

CHAPTER X

THE DRAWINGS AND THE SHOP

150. The test of any working drawing for legibility, completeness and accuracy is the production of the object or assembly by the shop without further information than that given on the drawing. The draftsman's knowledge of shop methods will to a great extent govern the effectiveness and completeness of the dimensioning and notes; the proper specification of machining operations, heat treatment and finish; the accuracy to be maintained on mating parts; and in some cases the order of machining. The young draftsman, whenever opportunity permits, should follow operations through the shops, get acquainted with shop men and enlarge his knowledge by reading and discussion. The glossary of shop terms, page 607, should be studied, in connection with the dimensioning and notes on the various working drawings in this book, to gain an acquaintance with the terms and the form of designation in the notes. This chapter is thus given as an introduction to the one following on dimensions and notes.

The relation of drawings, and the prints made from them, to the operations of production is illustrated in the graphical chart, Fig. 415, which shows in diagrammatic form the different steps in the development of the drawings, and their distribution and use in connection with the shop operations, from the time the order is received until the finished machine is delivered to the shipping room.

151. The Drawings.—Figure 416 is a complete working drawing, with shape and size description, and giving, where needed, the operations that are to be performed by the shop. Finished surfaces are clearly indicated, and dimensions are placed so as to be useful to the various shops, without requiring the adding or subtracting of dimensions or scaling the drawing.

152. The Pattern Shop.—In the title of the drawing, Fig. 416, the material specified is cast iron, which clearly indicates that the drawing must first be sent to the patternmaker, who will make a pattern in wood. From this, if a large quantity of castings is required, a metal pattern, often in "white metal," is made. The patternmaker provides for the shrinkage of the casting by making the pattern oversize, using a "shrink rule" for his measurements, and allows extra metal for machining the finished surfaces. He also provides the "draft" or slight taper, not shown on the drawing, so that the pattern can be withdrawn easily from the sand. A "core box," for the making of sand cores for the hollow parts of the casting, is also made in the pattern shop. A knowledge of patternmaking is of great aid in dimen-

sioning, as almost all the dimensions are used by the patternmaker, while only a few (dimensions to finished surfaces, location and size of finished holes, etc.,) are used by the machine shop.

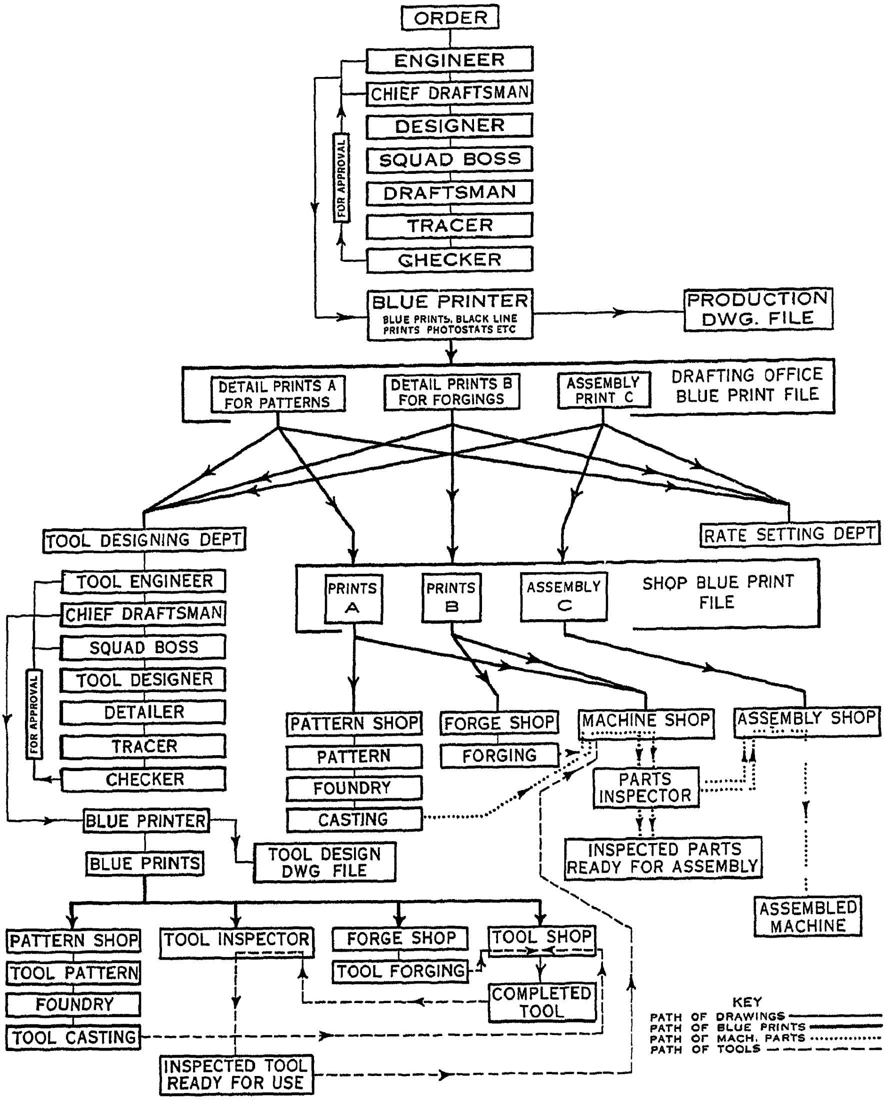


FIG. 415.—Development and distribution of drawings.

153. The Foundry.—The pattern and core box are sent to the foundry, and sand molds made so that molten metal may be poured into them and allowed to cool, forming the completed rough casting. Figure 417 shows a cross section of a two-part mold, showing the space left by the pattern, and the core in place. Only in occasional instances does the foundryman call for

assistance from the drawing, as his job is simply to reproduce the pattern in metal.

154. The Forge Shop.—In many cases the rough piece will be of wrought iron or steel, formed either by hand forging, or by drop forging, where forging dies are made to produce the shape wanted. In general, separate forging drawings are made for this work.

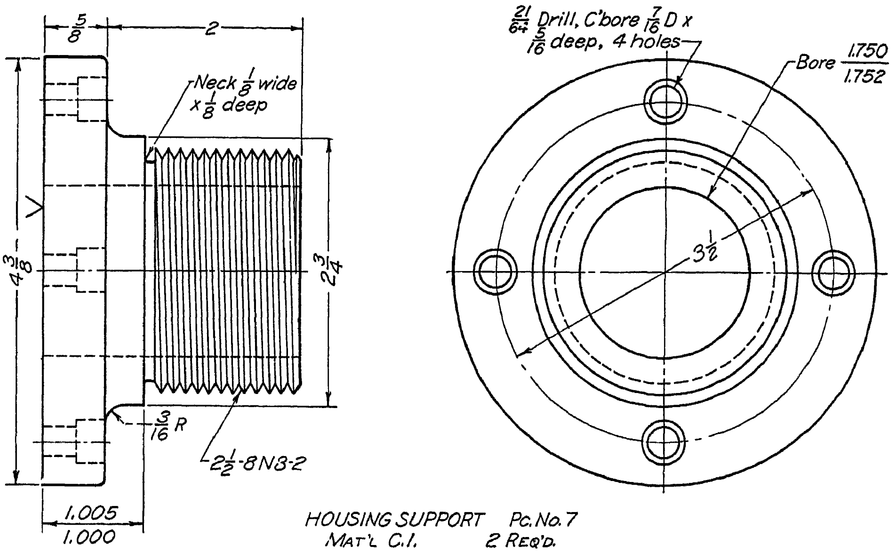


FIG. 416.—A working drawing.

155. The Machine Shop.—The rough castings or forgings come to the machine shop to be finished according to the drawing specifications. Flat surfaces are machined on a planer, shaper or milling machine and, in some cases (facing), on a lathe. Holes are drilled, reamed, counterbored and countersunk on a drill press or lathe; holes are bored on a boring mill or lathe. For exact work, grinding machines with wheels of abrasive material are used, and grinders are coming into greatly increased use also for operations formerly made with cutting tools. In quantity production many special machine tools and automatic machines are in use. The special tools, jigs and fixtures made for the machine parts are held in the toolroom ready for the machine shop.

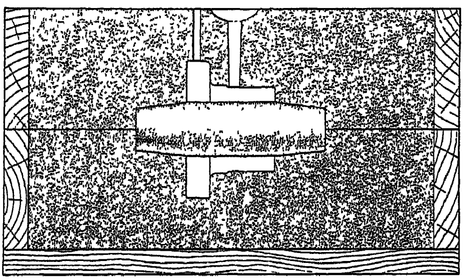


FIG. 417.—Cross section of two-part mold.

156. Fundamentals of Machining.—All machining operations remove metal, either to make a smoother and more accurate surface, as by planing

or turning; or to produce a surface not previously existing, as by drilling, punching, etc. The metal is removed by a hardened steel cutting tool (machining) or an abrasive wheel (grinding), the product or "work" as well as the tool or wheel being held and guided by the machine. When ordinary cutting tools are used the product must remain soft until after all work has been performed upon it, but if aluminum oxide or carborundum grinding wheels are employed the product may be hardened or heat-treated before finishing.

All machining methods may be classified according to the operating principle of the machine performing the work.

1. The surface may be *generated* by moving the work with respect to a cutting tool, or the tool with respect to the work, following the geometric laws for producing the surface.
2. The surface may be *formed* with a specially shaped cutting tool, moving either work or tool while the other is stationary.

The forming method is, in general, less accurate than the generating method, as any irregularities in the cutter are reproduced on the work. In some cases a combination of the two methods is used.

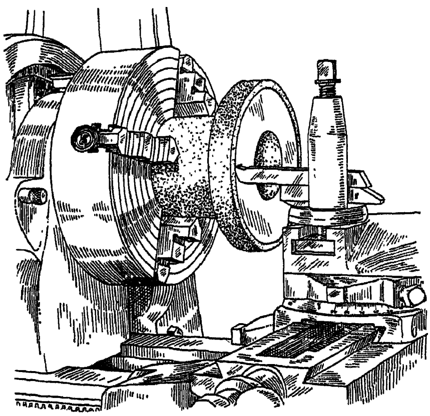


Fig. 418.—Facing.

157. The Lathe.—Called the "king of machine tools," it is said that the lathe is capable of producing all other machine tools. Its primary function is for machining cylindrical, conical and other surfaces of revolution, but with special attachments a great variety of operations can be performed. Figure 418 shows the casting, made from the drawing of Fig. 416, held in the lathe chuck. As the work revolves, the cutting tool is moved across perpendicular to the axis of revolution, removing metal from the base and producing a plane surface by generation. This operation is called *facing*. After being faced, the casting is turned around, and the finished base is aligned against the face of the chuck, bringing the cylindrical surface into position for *turning* to the diameter indicated in the thread note on the drawing. The neck shown at the intersection of the base with the body is turned first, running the tool into the casting to a depth slightly greater than the depth of the thread. The cylindrical surface is then turned (generated) by moving the tool parallel to the axis of revolution, Fig. 419. Figure 420 shows the thread being cut on the finished cylinder. The tool is ground to the profile of the thread space, carefully lined up to the work and moved parallel to the axis of revolution by the lead screw of the lathe.

This operation is a combination of the fundamental processes, as the thread profile is formed, while the helix is generated.

The hole through the center of the casting, originally cored, is now finished by *boring*, as the cutting of an interior surface is called, Fig. 421.

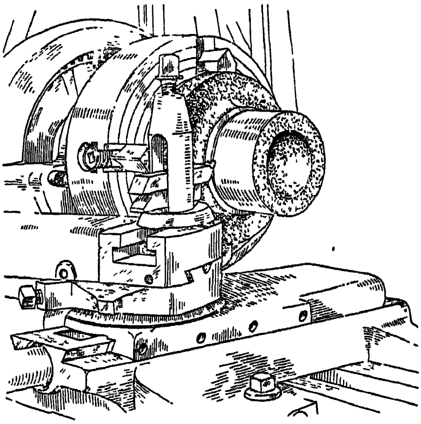


FIG. 419.—Turning.

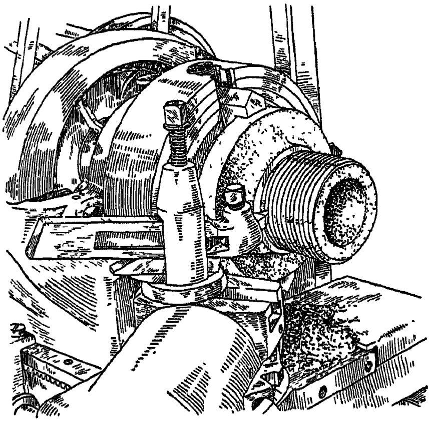


FIG. 420.—Threading.

The tool is held in a boring bar and moved parallel to the axis of revolution, thus generating an internal cylinder.

Note that in these operations the dimensions used by the machinist have been (1) the height dimension and finish mark on the base, (2) the

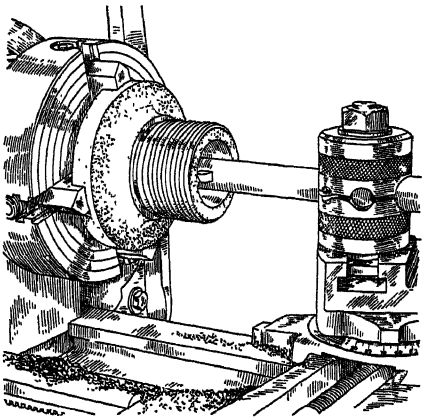


FIG. 421.—Boring.

thread note and outside diameter of the thread, (3) the dimensions of the neck, (4) the distance from the base to the shoulder, and (5) the diameter of the bored hole.

158. The Drill Press.—The partially finished piece is then taken to the drill press for drilling and counterboring the holes in the base according to

the dimensions on the drawing, which give the diameter of the drill, the diameter and depth of the counterbore and the location of the holes. The casting is clamped to the drill-press table, Fig. 422, and the rotating drill brought into the work by a lever operating a rack and pinion in the head of the machine. The cutting is done by two ground lips on the end of the

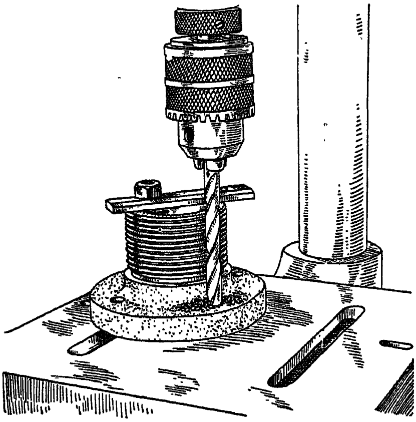


FIG. 422.—Drilling.

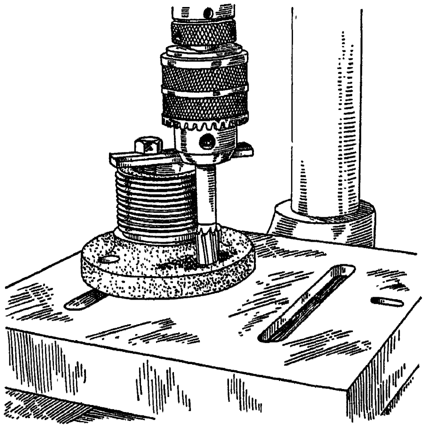


FIG. 423.—Counterboring.

drill. Drilling can be done in a lathe, the work revolving while the drill is held in, and moved by, the tailstock. In Fig. 423 the drill has been replaced by a counterboring tool whose diameter is the size specified on the drawing, and which has a pilot on the end to fit into the drilled hole and ensure concentricity. This tool is fed in to the depth shown on the drawing.

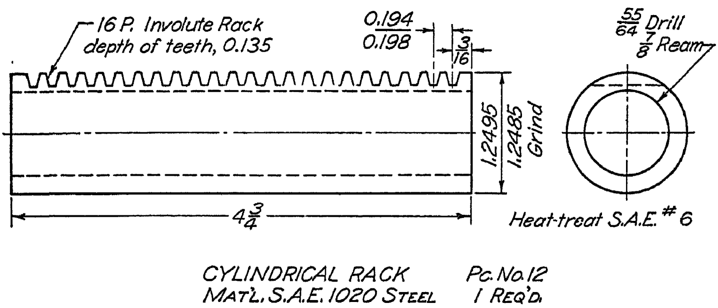


FIG. 424.—A working drawing

Study the drawing of Fig. 416 with the illustrations of the operations, and check, first, the dimensions that would be used by the patternmaker, and, second, those required by the machinist.

159. The Turret Lathe.—Figure 424 is the detail drawing of a cylindrical rack. The material is cold-rolled steel, and the size shows that the piece may be worked from standard stock. The inside diameter is marked *drill* and *ream*, which indicates, for quantity production of this type of object, a

turret-lathe operation. The cold-rolled steel stock is held in the collet chuck of the turret lathe and the end surface faced off, and the piece is then ready for drilling and reaming. The turret holds the various tools and swings them around into position as needed. A center drill starts a small hole to align the larger drill and then the drill and reamer are brought successively

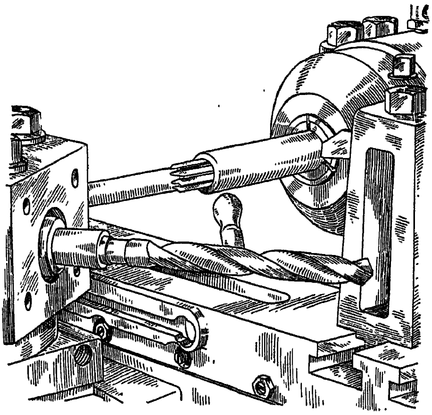


FIG. 425.—Reaming.

into position. The drill provides a hole slightly undersize, and then the reamer, cutting with its fluted sides, cleans out the hole to size and leaves it with a smooth, accurate finish. Figure 425 shows the turret indexed so that the drill is out of the way and the reamer is in position. At the right is seen the cut-off tool ready to cut the piece to the length shown on the drawing.

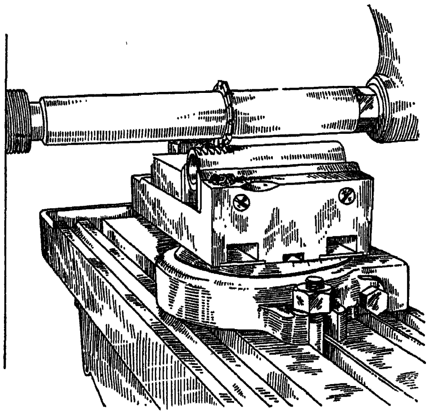


FIG. 426.—Milling.

160. The Milling Machine.—The dimensions of the cylindrical rack, Fig. 424, give the depth and spacing of the cuts and also the cutter to be used, since this type of work is usually done on a milling machine. The work is held in a vise and slowly moved into the rotating tool (milling cutter), Fig. 426, which in profile is the shape of the space between the teeth. The cuts are spaced by moving the table of the machine to correspond with the dis-

tance shown on the drawing. With several cutters mounted together (gang milling), a number of teeth can be cut at one time. Note that this operation is a forming process, as the shape depends upon the contour of the cutter.

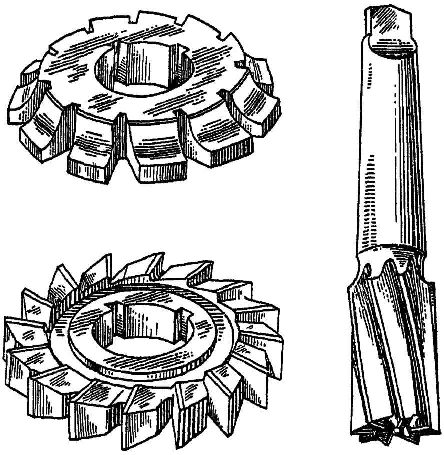


FIG. 427.—Milling cutters.

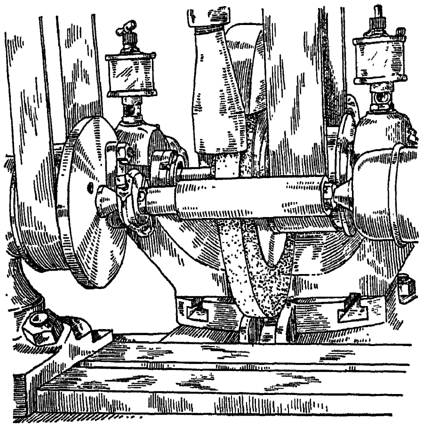


FIG. 428.—Grinding.

There are many types of milling cutters made, for forming flat, curved and special surfaces. Some cut on their periphery, some on their ends. An end mill is similar to the counterboring tool of Fig. 423. Three milling cutters are shown in Fig. 427.

161. The Grinder.—The limit dimensions on the cylindrical rack drawing indicate an accurate surface. The general purpose of grinding is to make a smoother and more accurate surface than can be obtained by turning, facing, planing or milling.

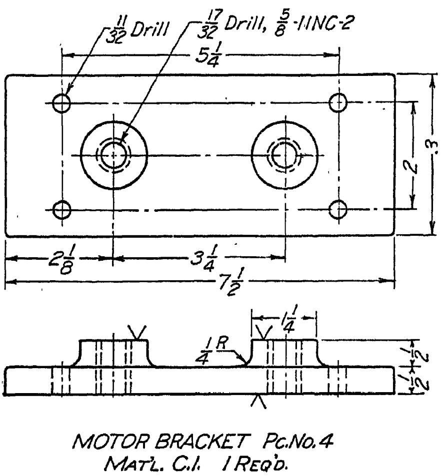


FIG. 429.—A working drawing.

In many cases, pieces hardened by heat-treatment will warp slightly. As ordinary machining methods are impossible with hardened materials, such pieces are finish-ground after hardening. Figure 428 shows a grinding operation. The abrasive wheel rotates at high speed, and the work rotates slowly in the opposite direction. The work is gaged carefully during the operation, to bring the final size within the limits shown on the drawing and to check for a perfect cylindrical surface without taper. The machine for cylindrical work is called a "cylindrical grinder," while one for flat surfaces is called a "surface grinder."

162. The Shaper and the Planer.—Figure 429 is the detail drawing of a motor bracket, showing base and boss surfaces marked with the finish symbol indicating rough machining. A flat surface of this type may be machined on a shaper or a planer. In this case the shaper is used because of the relatively small size of the part, Fig. 430. The tool is held in a ram which moves back and forth across the work, taking a cut at each pass forward. Between the cuts the table moves laterally, so that closely spaced parallel cuts are made until the surface is machined.

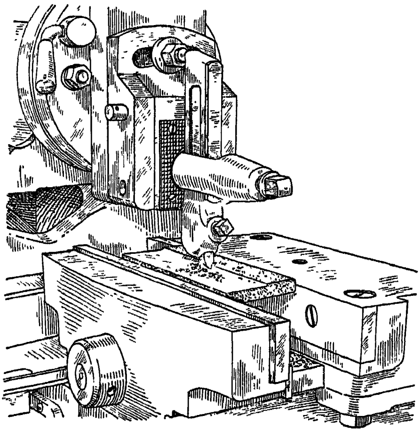


Fig. 430.—Shaping.

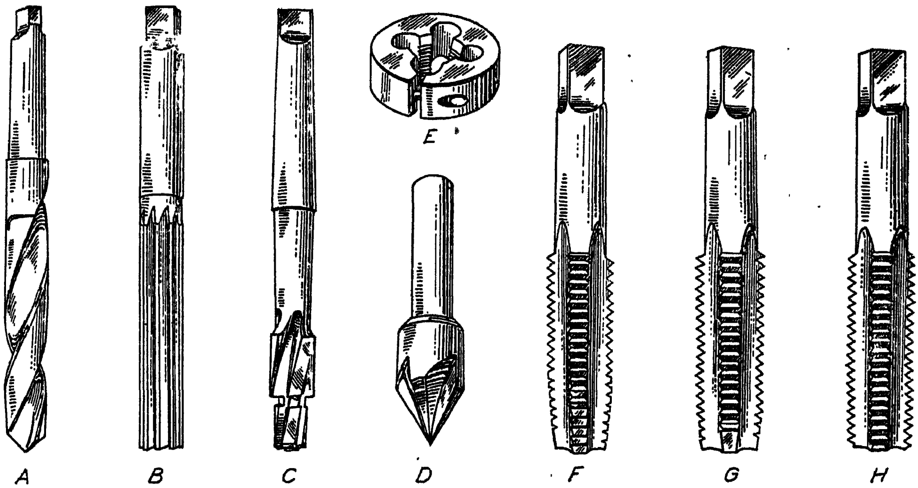


Fig. 431.—Various tools.

The planer differs from the shaper in that its bed, carrying the work, moves back and forth under a stationary tool. It is generally used for a larger and heavier character of work than that done on a shaper.

163. Small Tools.—The shop uses a variety of small tools, both in powered machines and as hand tools. Figure 431 shows at *A* a twist drill, at

B a reamer, at *C* a counterbore and at *D* a countersink. A die for threading a rod or shaft is shown at *E*, and *taper*, *plug* and *bottoming* taps at *F*, *G* and *H* for cutting the thread of a tapped hole. Holes are often machined by broaching. A broach is a long toothed bar, which is pulled or pushed through a hole, each of the serrated edges successively cutting metal away until the last edge forms the shape wanted. Figure 432 shows four different forms.

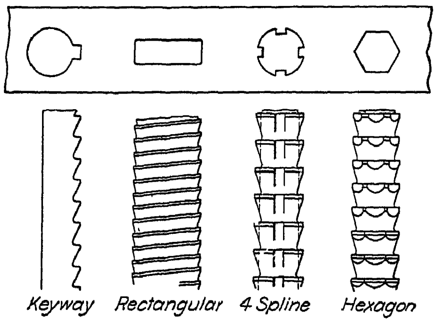


FIG. 432.—Broaches.

164. Inspection Department.—Careful inspection is an important feature of modern production. Good practice requires inspection after each operation. The term "preventive inspection" is used as meaning the inspection of the first piece of each setup before the operator is allowed to proceed.

165. Assembly Shop.—The finished separate pieces come to the assembly shop to be put together according to the assembly drawings. Sometimes it is desirable or necessary to perform some small machining operation during assembly, usually drilling or rough grinding. In such cases the assembly drawing should carry a prominent note explaining the required operation, and give dimensions for the alignment or location of the pieces. When a complete assembly drawing is not used, a suitable note should be placed on the detail drawing of each piece, as "½ drill in assembly with piece No. 107."

CHAPTER XI

DIMENSIONS AND NOTES

166. After the *shape* of the object has been described (orthographic or pictorial) the value of the drawing for the construction of the object depends upon the dimensioning and notes to tell the *size*. Here our study of drawing as a language must be supplemented by a knowledge of shop methods. The machine draftsman to be successful must have an intimate knowledge of patternmaking, foundry practice, forging and machine-shop practice, as well as, in some cases, sheet-metal working, metal and plastic die-casting, welding and structural-steel fabrication.

The beginning student without this knowledge should not depend upon his instructor alone, but, as recommended in the previous chapter, should set about to inform himself regarding the elements of the patternmaker's and founder's work, and the uses of ordinary machine tools, observing work going through the shops and reading books and periodicals on methods and materials used in modern machine-shop practice and machine production.

The dimensions put on the drawing are not necessarily those used in making the drawing, but those necessary and most convenient for the workmen who are to make the piece. The draftsman must thus put himself in the place of the patternmaker, foundryman, blacksmith and machinist, and mentally construct the object represented, to see if it can be cast, forged or machined practically and economically, and what dimensions would give the required information in the best way. In brief, careful consideration of all the operations of the various workmen on the actual object is necessary.

167. Lines and Symbols.—A size may be given by means of a dimension, complete with figures to show the actual measurement, but when it is necessary to give a machining operation or similar information a leader and note is used. Complete dimensions are made up of dimension lines, arrowheads, extension lines, leaders, figures, notes and finish marks.

Dimension lines are made with fine full lines, so as to contrast with the heavier outline of the drawing. They are terminated by carefully made arrowheads at the ends of the dimension line. Arrowheads are drawn with a fine lettering pen on each dimension line just before the figures are added, making the sides either in one stroke, or in two strokes from the point, as shown in enlarged form in Fig. 433. The general preference is for the filled-in head, which is best made by first setting the length with a short curved stroke as shown in Fig. 434. The size of the arrowhead varies somewhat with the size of the drawing but $\frac{1}{8}$ inch is a good general length.

The width at the base should not be more than one-third the length. All arrowheads on the same drawing should be the same size, except in restricted spaces. Avoid the incorrect shapes shown in Fig. 435. In machine-draw-

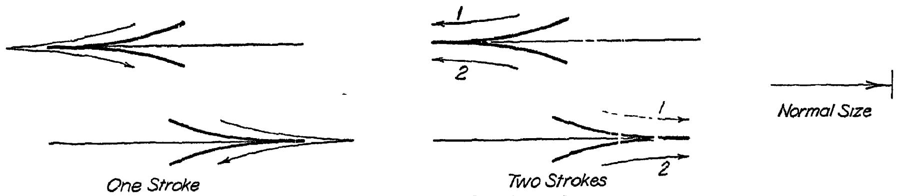


FIG. 433.—Arrowhead strokes.

FIG. 434.—Stages in making the filled-in arrowhead.

ing practice a space is left in the line for the figures. It is universal in structural practice and is very common in architectural practice to place the figures above a continuous dimension line as in Fig. 436.

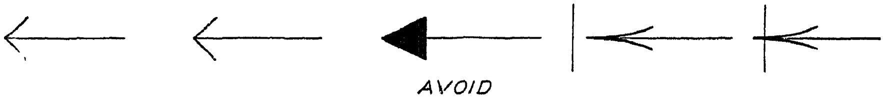


FIG. 435.—Incorrect arrowheads.

FIG. 436.—Placing figures.

Dimensions are preferably kept outside the views, but occasionally may be placed to better advantage inside. Thus dimension lines will terminate either at extension lines or center lines or visible outlines of the view.

Extension lines are fine, long-dash lines extending outside the view to show the distance measured. They should not touch the outline but should start about $\frac{1}{16}''$ from it and extend about $\frac{1}{8}''$ beyond the last dimension line, Fig. 437.

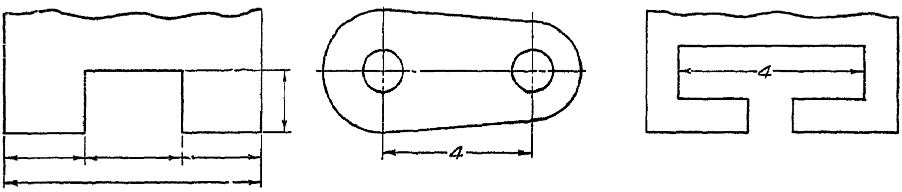


FIG. 437.—Dimension terminals.

Where a measurement between centers is to be shown, center lines are used for extension lines, extending about $\frac{1}{8}''$ past the dimension line.

The outline of the view becomes the terminal for arrowheads when dimensions must be placed inside the view. This might occur because of limited space or when extension lines would be very long, making the dimension hard to read.

Leaders are made up of fine straight ruled lines, with an arrowhead touching the contour view or edge of the surface to which a note or dimension applies. When several are used they should be kept parallel if possible. The usual angle is 60° with the horizontal, Fig. 438.

The note end of the leader should always run either to the beginning or end of the note, never to the middle.

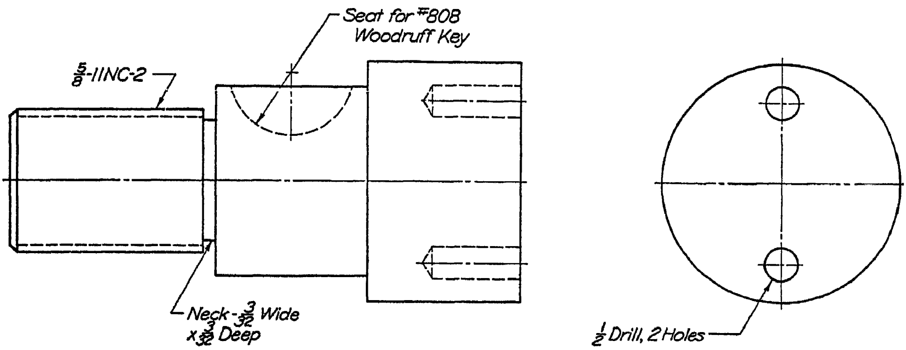


FIG. 438.—Leaders and notes.

Figures must be carefully lettered in either vertical or inclined style. In an effort for neatness the beginner often gets them too small. One-eighth inch is a good general height.

Fractions must be made with a division line in line with the dimension figure, and with figures two-thirds the height of the whole numbers, so that the total height is one and two-thirds that of the whole number.

Feet and inches are indicated thus: 5′-6″. When there are no inches it should be so indicated, as 5′-0″, 5′-0½″. When dimensions are all in inches the inch mark is preferably omitted from all the dimensions and notes.

168. Finish marks are used to indicate that certain surfaces of metal parts are to be machined, and that allowance must therefore be made on the casting or forging for finish. They are not necessary on parts made from rolled stock or on surfaces machined from the solid, as spot faces, and drilled, reamed, counterbored or countersunk holes, except where a note does not give the operation. The finish mark is necessary if surface roughness is to be specified.

The ASA recommends a 60° V with its point touching the line representing the surface to be machined, placed on all views which show the surface as a line, including dotted lines. If the piece is to be finished all

over, the note "Finish all over" is used and the marks on the views omitted. Figure 439 illustrates the use of the finish mark.

Surface Roughness.—The ASA proposes (ASA B46) a set of symbols to indicate the roughest surface acceptable. The symbol is a number placed in the open end of the V, which indicates the root-mean-square height of irregularities in microinches. Thus $\overset{16}{\vee}$ indicates that the roughness must not exceed 16 microinches. The finish mark and roughness symbol are illustrated in Fig. 440.

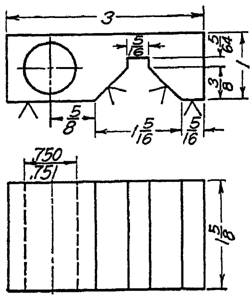


FIG. 439.—ASA finish mark.

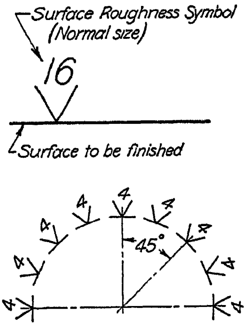


FIG. 440.—Surface roughness symbol.

Master gages for surface roughness may be made up, measured and marked with the roughness symbol, and comparison made with these gages visually, either with or without optical apparatus, and by the sense of touch. This ability to make accurate measurement of roughness permits precise specification of the surface required. The accompanying table gives preferred roughness symbols and type of surface to which they apply.

ASA SPECIFICATIONS FOR SURFACE ROUGHNESS

Roughness symbol	Root mean height of irregularities, microinches	Type of surface, approximate
63 M 16 M 4 M	63,000 16,000 4,000	Rough castings and machining operations where furrows are clearly visible and easily felt
1 M 250 63	1,000 250 63	Turning, boring and milling operations.
32 16 8	32 16 8	Diamond or hard-metal turning and boring, finish grinding, honing, smooth molding
4 2 1	4 2 1	Very fine grinding, honing, lapping
½ ¼	½ ¼	Highly polished finishes

169. Old Finish Mark.—The symbol which has been in use for many years is an italic *f* with its cross mark intersecting the line, Fig. 441. This mark is difficult to make, mars the appearance of the drawing, is entirely inadequate and is not recommended.

170. Theory of Dimensioning.—Any object, no matter how complicated, can be "broken down" into a combination of simple geometrical shapes, principally prisms and cylinders, with occasionally parts of pyramids and

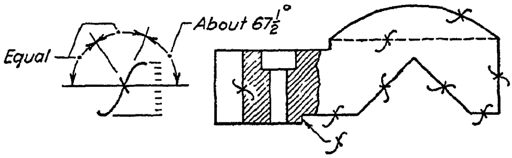


FIG. 441.—Finish mark.

cones, now and then a double curved surface and very rarely (except for surface of screw threads) a warped surface. If the *size* of each of these elemental shapes is dimensioned and the relative location of each is given, measuring from center or base lines or from the surfaces of each other, the dimensioning of any piece can be done systematically and simply. Dimensions may thus be classified as *size dimensions* and *location dimensions*.

171. Size Dimensions.—As every solid has three dimensions, each of the geometrical shapes making up the object must have its height, width and

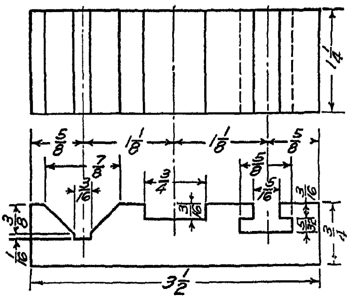


FIG. 442.—Contour rule applied.

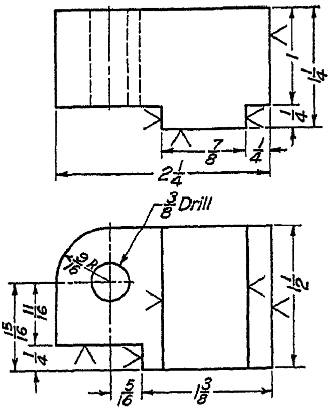


FIG. 443.—Contour rule applied.

depth indicated in the dimensioning. The commonest shape met with is the *prism*, usually in plinth or flat form. The universal rule is: *give two of the three dimensions on the view showing the contour shape, and the third one on one of the other views.* Analyze Figs. 442 and 443, then Fig. 446.

The second most common shape is the *cylinder*, found on nearly all mechanical pieces as a shaft or a boss or a hole. A cylinder obviously requires only two dimensions, diameter and length. Although it cannot be stated as a rule, it is good practice to give the diameter and length on the

same view, Fig. 444. An exception to this is in the case of "negative cylinders," or holes, in which the diameter and operation are better given together as a note on the contour view, as in Figs. 443 and 444. The contour rule also applies to all partial cylinders, such as rounded corners and fillets, whose radii must be given on the view that shows their shape.

Cones may be dimensioned with the altitude and diameters on the same view. They usually occur as frustums or as tapers.

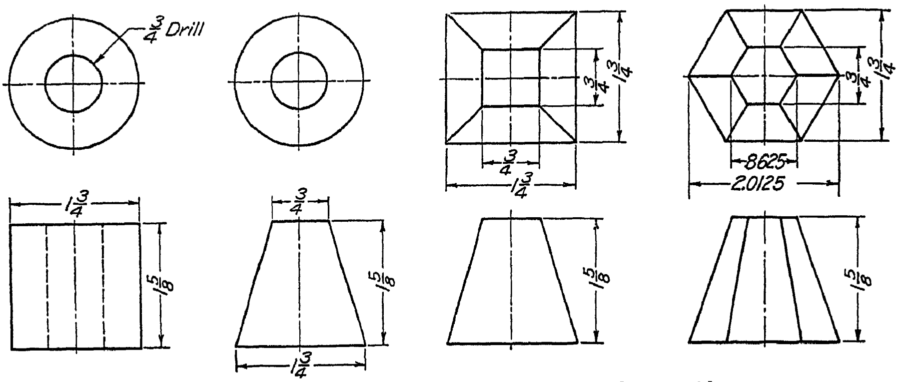


FIG. 444.—Dimensioning cylinders, cones and pyramids.

Taper per foot means the difference in diameters or in widths in 1 foot of length. In dimensioning a taper when the slope of the taper is specified, the length and one diameter are given, or both diameters may be given, omitting the length of the tapers, Fig. 445. See Appendix for taper dimensions.

Pyramids should have two of their three dimensions given on the view that shows the shape of the base.

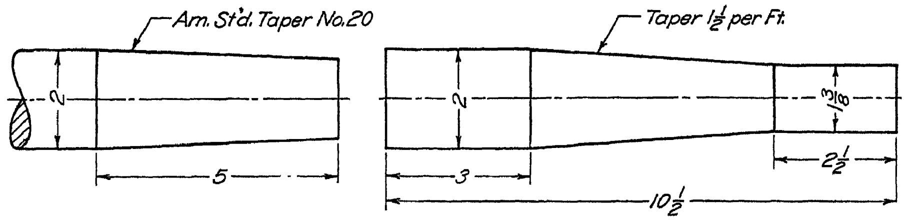


FIG. 445.—Dimensioning tapers.

Spheres are dimensioned by giving the diameter on the most convenient view; other surfaces of revolution by dimensioning the generating curve.

Warped surfaces are dimensioned according to their method of generation, and as their representation requires numerous sections, each of these must be fully dimensioned.

172. Location Dimensions.—The selection and placing of location dimensions requires even more thought than do size dimensions. The

operations used in making the piece and the way it fits with other pieces must be kept constantly in mind.

When the size dimensions of some portion of the object are being placed, the location of that portion must also be considered, so as to eliminate the shifting of some size dimension to make room for a location dimension. The method of construction, the accuracy demanded and the relation of the portion to other elements of the unit or machine must be carefully considered. Illustrating with Fig. 446, the size dimensions of the base are placed so that the location dimension of the two spot-faced holes may be put *inside* the size dimension. *Relationship* of the two bearings to the integral spline is indicated by the vertical location dimensions giving the distance from the spline to the upper bearing and the distance between the bearings.

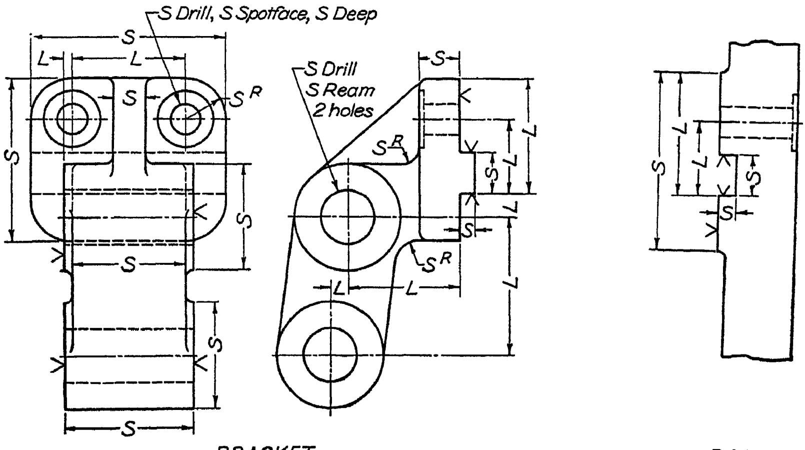


Fig. 446.—Size and location dimensions.

Machining operations are given for the holes in the base and the bearings. These should indicate the *accuracy* demanded, as well as the method of manufacture. Note that the placement of the size dimensions is dependent somewhat upon the placement of the location dimensions. Thus the two types of dimensions must be considered together and the best arrangement worked out, so that there will be a minimum of leaders crossing each other and no unnecessary crowding of dimensions, and so that each dimension is placed where it is readily found and easy to read.

On the drawing of the piece to which this support bracket is to be bolted, all vertical location dimensions would be given to the lower surface of the slot on which the bracket spline rests when the two pieces are assembled, as shown in the figure.

Flat surfaces are located from center lines or from base lines representing the edges of finished surfaces. Every circle representing a cylinder or hole will have two center lines at right angles. Locate the axis by dimensioning

from these center lines, as in Figs. 446 and 447. In general, location dimensions are made from either a finished surface or a center line. With rough castings or forgings a basic surface should be selected or a center line assumed.

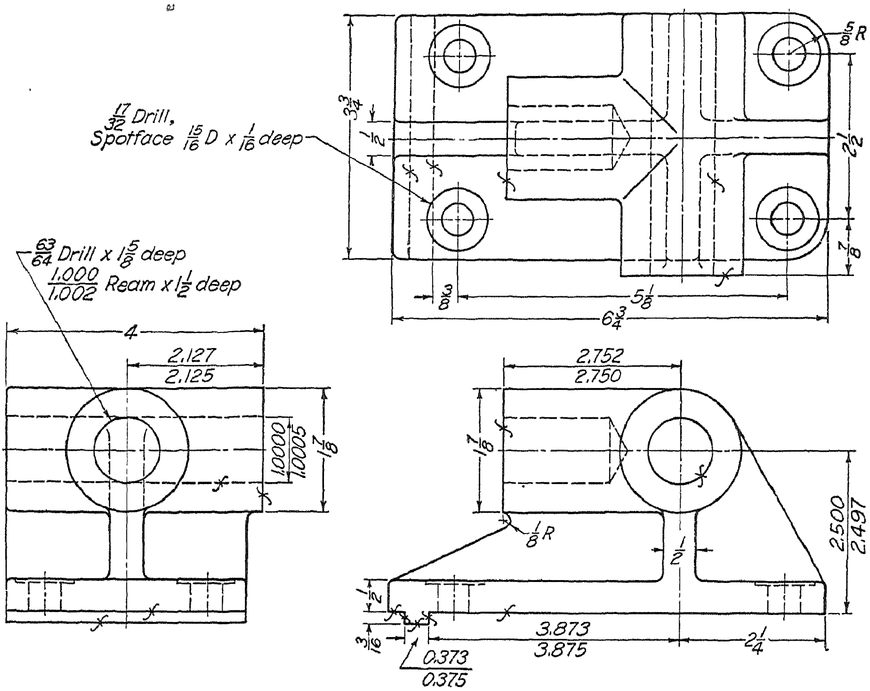


FIG. 447.—An example of dimensioning (angle shaft bracket).

173. Systematic adherence to these principles of dimensioning will give an assurance and confidence that the drawing is properly and completely dimensioned. Not only will all the necessary dimensions thus be given, but any unnecessary ones will not even be considered.

The ability to think in three dimensions, emphasized in previous chapters, is of just as much importance in size description as in shape description. Unless one can look at the drawing and see the object, it will be difficult to apply this theory of dimensioning intelligently.

174. Placing Dimensions.—A systematic order of working is of great help in placing dimensions. Figure 448 will illustrate the procedure. At *A* the shape description is complete. *B* shows the extension lines placed and center lines extended where necessary, thus planning for the positions of both size and location dimensions is started. At *C* the dimension lines have been added. Here the placement of the dimensions is fixed, and size and location dimensions are worked along together to get the best combination. Next, arrowheads and leaders for notes are drawn as at *D*. Figures

are then added and notes lettered as at *E* and *F*. Be careful not to crowd dimension lines. Keep them at least ¼ inch away from the drawing and from each other.

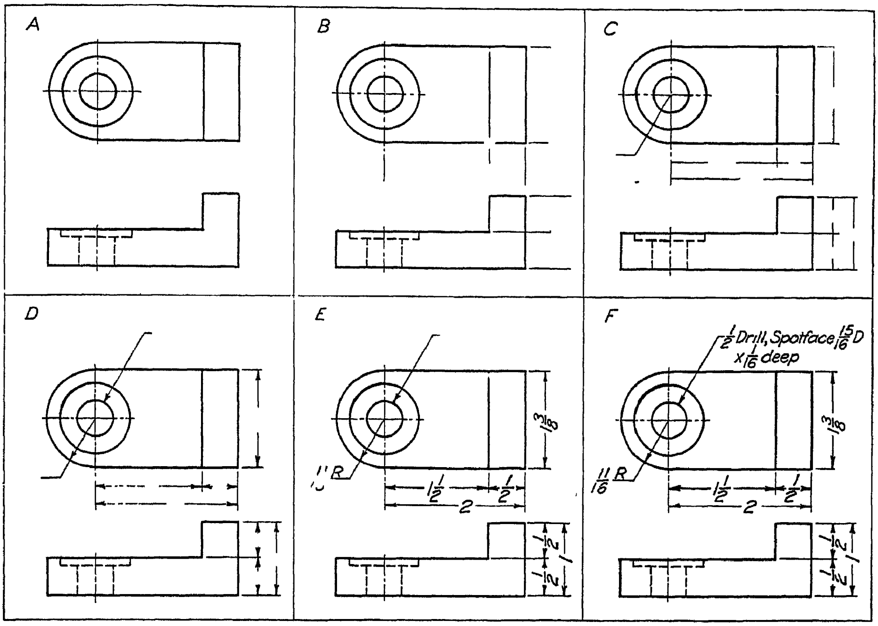


FIG. 448.—Order of dimensioning.

The following general rules, grouped for convenience, should be observed.

RULES FOR DIMENSIONING

1. Horizontal and sloping dimensions should read from left to right and **vertical dimensions** from bottom to top, that is, the drawing should be readable from the bottom and right side. See Fig. 449.

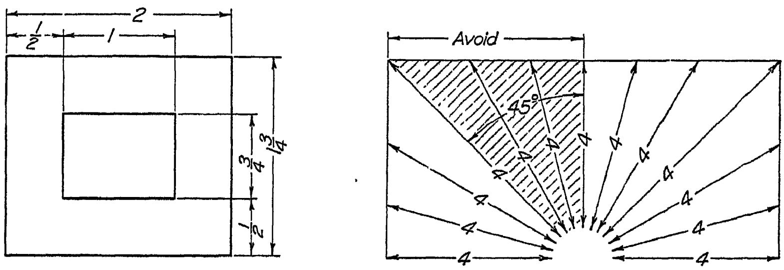


FIG. 449.—Placing figures.

Avoid running dimensions in a direction included in the shaded area. If this is unavoidable they should read downward with the line.

In the automotive and aircraft industries a common practice is to have *all* dimensions and notes read from the bottom of the drawing. This method is of advantage on large drawings, which can thus be read easily without turning the drawing or the head. An example is shown in Fig. 450.

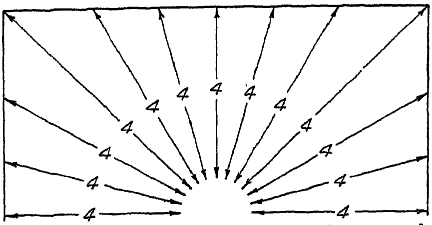


FIG. 450.—Placing figures, horizontal method.

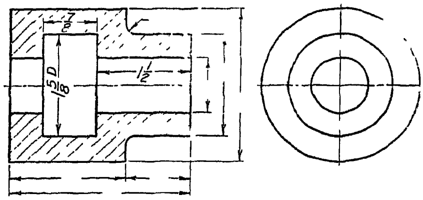


FIG. 451.—Dimensions inside the view.

2. Dimensioning outside the view is preferred, unless added clearness, simplicity and ease of reading will result from placing some of them inside. They should for appearance's sake be kept off the cut surfaces of sections. When it is necessary that they be placed there, the section lining is omitted around the numbers, Fig. 451.

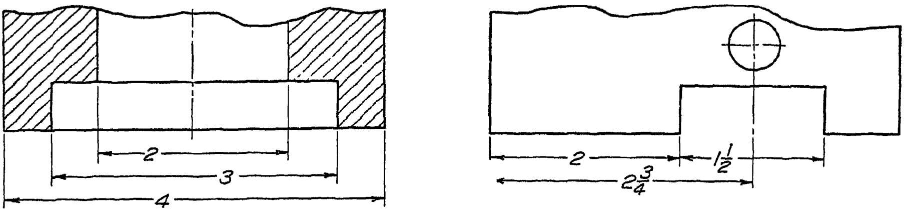


FIG. 452.—Staggered figures.

3. Dimensions between the views are preferred unless there is some reason for placing them elsewhere, as there was in Fig. 447, where the dimensions of the base of the angle shaft bracket must come at the bottom of the front view.

4. Parallel dimension lines should be spaced at equal distances and the figures staggered as in Fig. 452.

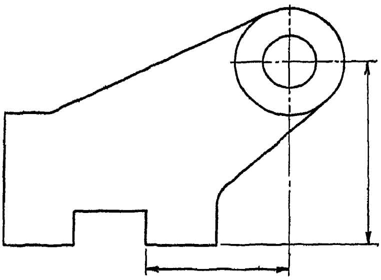


FIG. 453.—Location by offsets.

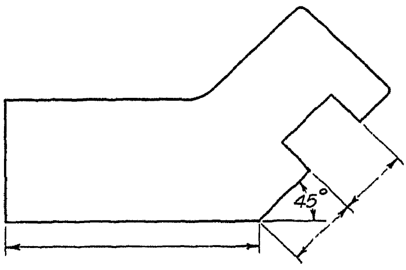


FIG. 454.—Location by angle.

5. Figures should be halfway between the arrowheads, except when a center line interferes or when several parallel dimensions are staggered.

6. Location dimensions should be given from finished surfaces to center lines, from center line to center line, or from finished surface to finished surface. Remember that rough castings or forgings will vary in size, and do not locate drilled holes or other machined shapes or surfaces from unfinished surfaces.

7. Location of a point or center by dimensioning from two center lines or surfaces is preferred over an angular dimension unless giving the angular dimension is more practical from the standpoint of construction, Figs. 453 and 454.

8. For equally spaced holes in a circular flange, give the diameter of the bolt circle, with the number and size of holes. See Fig. 667.

9. Give the diameter of a circle, not the radius; (drills, spot-facing tools, etc., are all specified by diameter, and the radius of any hole could not be easily measured). The dimension figure should be followed by the abbreviation D except when it is obvious that the dimension is a diameter. The diameter of a hole is frequently given in a note, Fig. 455.

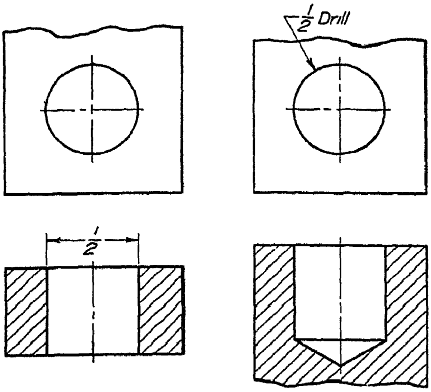


FIG. 455.—Dimensioning holes.

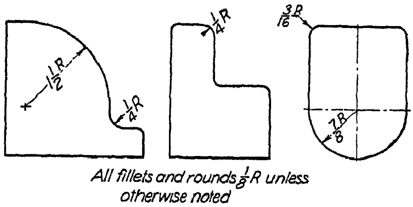


FIG. 456.—Radius dimensions.

10. Give the radius of an arc, followed by the letter R (a radius dimension line has no arrowhead at the arc's center). Small fillets and rounds are sometimes not dimensioned but taken care of by a general note. Radius dimensions should always be given at an angle, that is, not horizontal or vertical, Fig. 456.

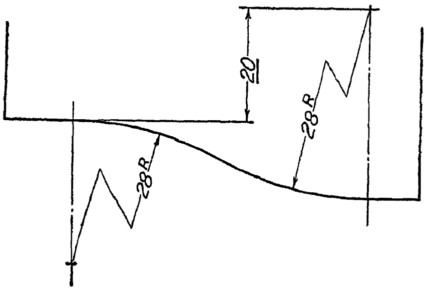


FIG. 457.—Inaccessible centers.

11. The center of an arc lying outside the limits of the drawing is given by showing the dimensions for the center and breaking the radial dimension line as in Fig. 457.

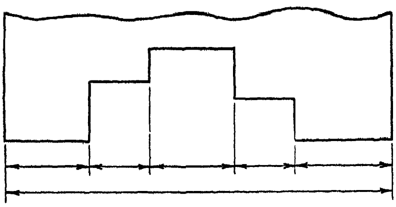


FIG. 458.—Continuous dimensions.

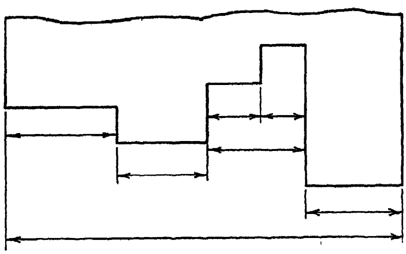


FIG. 459.—Staggered dimensions.

12. Continuous or staggered dimension lines may be used, depending upon convenience and readability. Continuous dimension lines are preferred, where possible. Figs. 458 and 459.

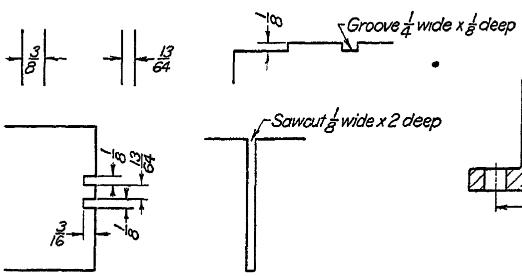


FIG. 460.—Limited space.

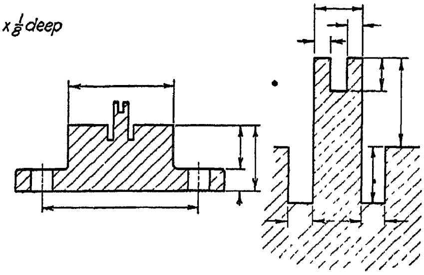


FIG. 461.—Use of enlarged section.

13. Always give the three over-all dimensions (a usual exception is with cylinders or pieces having cylindrical ends), placing them outside any other dimensions.

14. Dimensions should never be crowded. If the space is small, a note, or methods as illustrated in Fig. 460 may be used, or if still too small use a large removed section or part view. Fig. 461.

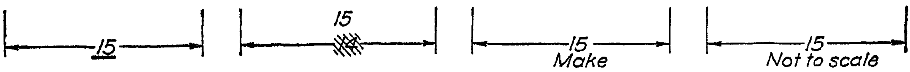


FIG. 462.—Revised dimensions.

15. Dimensions out of scale because the drawing has been revised or an error made in scaling may be indicated by one of the methods of Fig. 462. If several such changes occur on a drawing they should be listed in tabular form with reference letters.

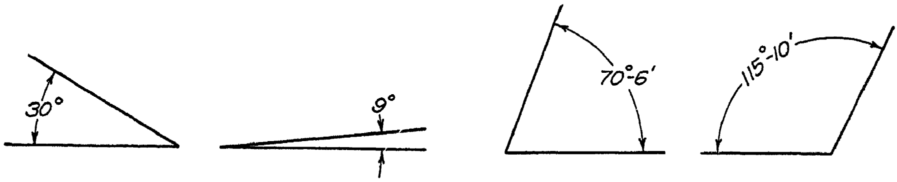


FIG. 463.—Dimensioning angles.

16. The dimension for an angle should be placed horizontally on an arc as a dimension line. Exception may be made for a large angle, placing the dimension in line with the arc, Fig. 463.

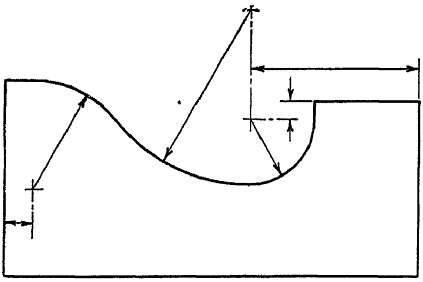


FIG. 464.—Dimensioning curves by radii.

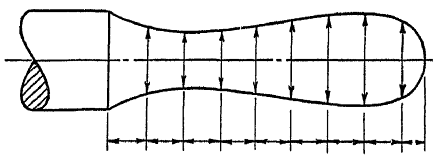


FIG. 465.—Dimensioning curves by offsets.

17. A curved line may be dimensioned by radii or by offsets, Figs. 464 and 465.

18. All notes should read horizontally (from the bottom of the sheet) if possible.

19. Decimal points, inches and feet marks, etc., should be made clearly and of ample size.

PRACTICES TO AVOID

1. Do not repeat dimensions unless there is a special reason for it.
2. Never give dimensions to the edge of a circular part but always from center to center or surface to center.
3. Never use a center line as a dimension line.
4. Never use a line of the drawing as a dimension line.
5. Do not allow a dimension line to cross an extension line unless unavoidable.
6. Never require a workman to add or subtract dimensions.
7. Never require a workman to scale a drawing.
8. Avoid dimensions to hidden lines whenever possible.

175. Shapes with rounded ends should be dimensioned according to their method of manufacture. Figure 466 shows six similar contours differ-

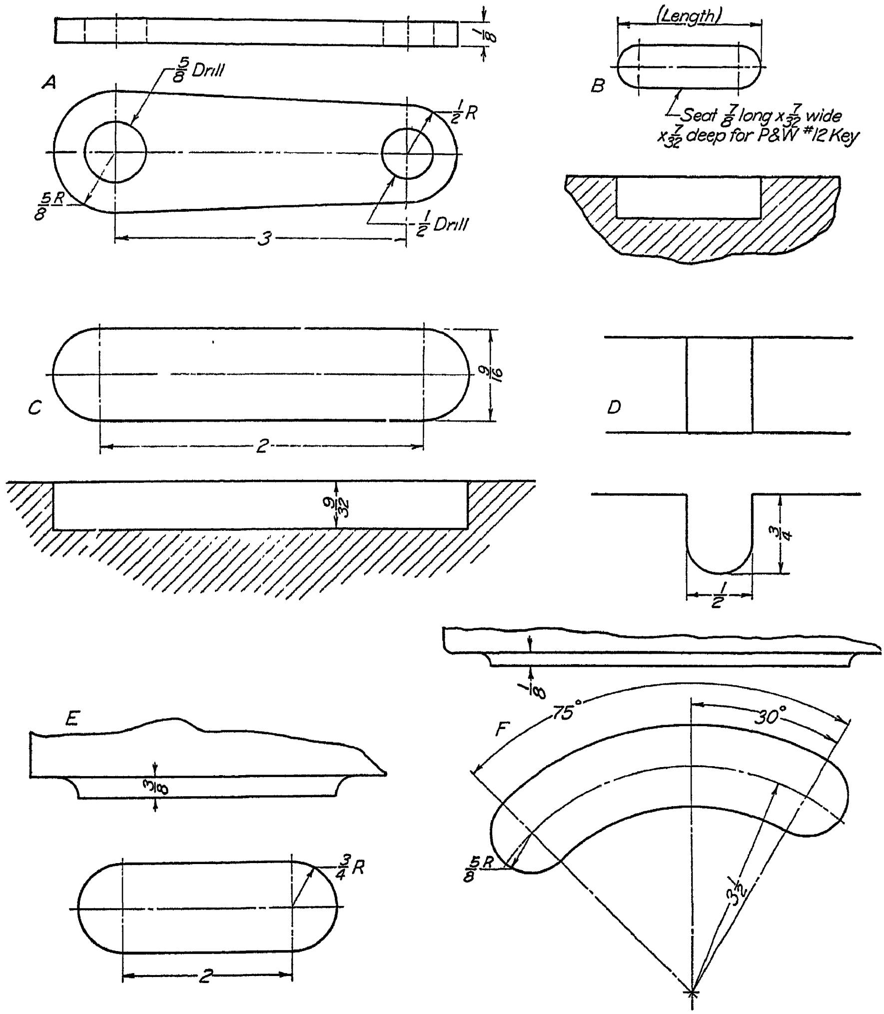


FIG. 466.—Dimensioning round end shapes.

ently dimensioned. The link *A* has the radius of the ends and the center distance given, as it would be laid out. *B* shows the contour of a Pratt and Whitney key seat. These keys are specified by their width and over-all length, and the key seat must be dimensioned to correspond. *C* shows a slot machined from the solid as with a milling machine. The given dimensions show the diameter of the cutter and the travel of the table. *D* shows a slot with rounded bottom, made with a milling cutter, the dimensions giving the width and depth of the cut. *E* and *F* show cast pads, dimensioned as they would be laid out by the patternmaker.

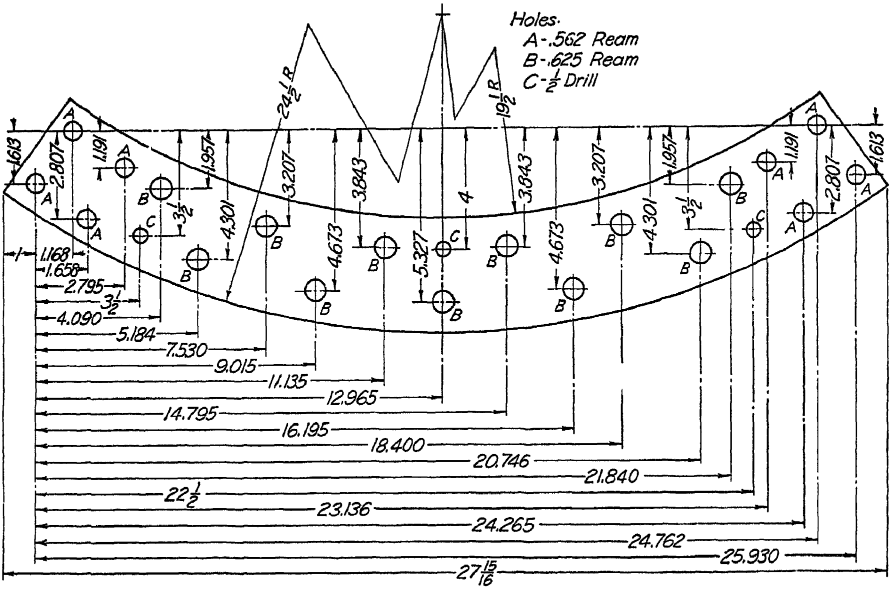


FIG. 467.—Base-line dimensioning.

176. Feet and Inches.—The ASA recommends that in machine-shop practice dimensions be given in inches up to 72 inches. In architectural work, dimensions over 12 inches are given in feet and inches. In structural practice, dimensions of 10 inches and over are given in feet and inches. In automotive practice all dimensions are given in inches.

177. Base-line Dimensioning.—This method, principally used in diemaking, jigs and fixtures, and other precision work, takes two finished edges at right angles or two center lines at right angles (usually the center lines of a hole nearest the edge), as base or reference lines and measures all dimensions from these lines. The jig plate, Fig. 467, is an example. The advantage of this method is that manufacturing errors will not be cumulative.

178. Dimensioning Threaded Parts.—The representation, dimensioning and notation of threaded parts according to the ASA are taken up in detail in the next chapter and hence are not given here.

179. Decimal Dimensioning.—In dimensioning any working drawing, he degree of accuracy required for various mating parts is an important onsideration. The proper functioning of the machine and the cost of it re to a great extent governed by the degree of accuracy necessary for the hop to maintain. If the dimension is given in fractions of an inch such as /2, 1/4, 1/8, 1/16, 1/32, 1/64, the machinist may use the common steel scale with /64 divisions, for measuring, and the accuracy expected is to the nearest /64 inch (that is, total variation is 1/64 inch, 1/128 inch under or over the limensioned size). If the dimension is given in decimal form, such as 2.000, the accuracy expected is to the nearest significant figure, or in this ase 0.001 inch (±0.0005). If the decimal is given to two places only, as 2.00, the accuracy expected would be 0.01 inch (±0.005).

180. Fits of Mating Parts.—With closely fitting parts the old practice vas to mark both parts with the same dimension and add a note, such as 'drive fit," "loose fit," etc., leaving the amount of allowance to the experince and judgment of the machinist. In modern practice the dimension or each piece is given in decimals to thousandths or ten-thousandths of an nch, the engineering department taking all the responsibility for the orrectness of the kind of fit required.

Since it is not possible to work to absolute accuracy, it is necessary in he modern system of quantity production with the requirement of "interhangeable assembly," to give these dimensions with "limits," that is, the naximum and minimum sizes within which the actual measurements must all in order to be accepted.

181. Allowances and Tolerances.—The five terms—"nominal size," 'basic size," "allowance," "tolerance" and "limits"—are so interconnected hat their meanings should be clearly understood before the study of limit imensioning is attempted.

The ASA gives the following definitions:

Nominal Size.—A designation given to the subdivision of the unit of length having no pecified limits of accuracy but indicating a close approximation to a standard size.

Basic Size.—The exact theoretical size from which all limiting variations are made.

Allowance (Neutral Zone).—An intentional difference in the dimensions of mating arts; that is, the minimum clearance space (or maximum interference) which is intended etween mating parts. It represents the condition of the tightest permissible fit, or the rgest internal member mated with the smallest external member. It is to provide for ifferent classes of fit.

Tolerance.—The amount of variation permitted in the size of a part.

Limits.—The extreme permissible dimensions of a part.

In illustration of these terms, suppose a 2″ shaft is to turn in a bushing. he *nominal size* is 2″. The *basic size* is the exact theoretical size of the ole, 2.000″. The *allowance* for the shaft to turn in the bushing may be ssumed as 0.003″. The *tolerance* on both shaft and bushing *may* be the same and in this case is taken as 0.001″. Applying the tolerance to the

bushing the size would be a minimum of 2.000 and a maximum of 2.000 + 0.001 = 2.001. The limits for the shaft would be the basic size minus the allowance (2.000 − 0.003 = 1.997) as the maximum, and this maximum minus the tolerance (1.997 − 0.001 = 1.996) as the minimum. These limits are put on the drawing as shown in Fig. 468.

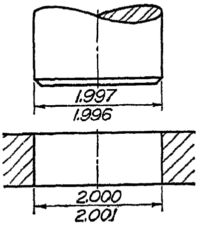


FIG. 468.

In this example the tightest fit possible (maximum shaft in minimum hole) is a clearance of 0.003″, and the loosest fit possible (minimum shaft in maximum hole) is a clearance of 0.005″.

The foregoing example is called the *basic hole* system, in which the minimum size of the hole is taken as a base from which all variations are made. Where a number of fits of the same nominal size are required on one shaft, as in line shafting, the *basic-shaft* system is used instead of the basic-hole system, using for the basic size the maximum diameter of the shaft.

Figure 469 is an example of limit dimensioning.

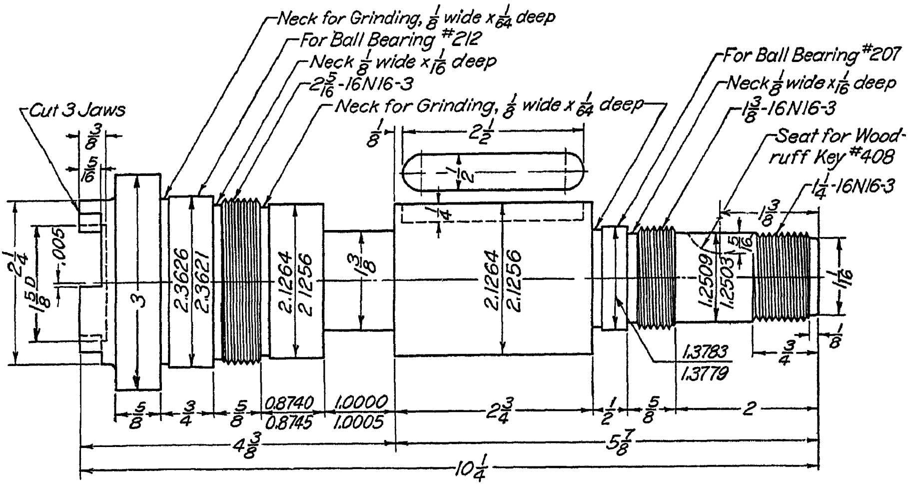


FIG. 469.—Limit dimensioning (clutch shaft).

182. Classes of Fits.—Different allowances must be made for different kinds of fits and in various classes of machinery. When one part is to move in another the allowance is positive; that is, the shaft would be smaller than the hole and there would be a "clearance" between them. If they are to be forced together the allowance is negative; that is, the shaft would be larger than the hole and there would be an "interference" of metal.

The ASA has made a classification of eight kinds of fits and has compiled tables of limits for external and internal members for different sizes in each class. These limits are tabulated in the Appendix.

ASA CLASSIFICATION OF FITS

Loose Fit (Class 1)—Large Allowance.—This fit provides for considerable freedom and embraces certain fits where accuracy is not essential.

Examples.—Machined fits of agricultural and mining machinery; controlling apparatus for marine work; textile, rubber, candy and bread machinery; general machinery of a similar grade; some ordnance material.

Free Fit (Class 2)—Liberal Allowance.—For running fits with speeds of 600 rpm or over and journal pressures of 600 pounds per square inch or over.

Examples.—Dynamos, engines, many machine-tool parts and some automotive parts.

Medium Fit (Class 3)—Medium Allowance.—For running fits under 600 rpm and with journal pressures less than 600 pounds per square inch; also for sliding fits and the more accurate machine-tool and automotive parts.

Snug Fit (Class 4)—Zero Allowance.—This is the closest fit which can be assembled by hand and necessitates work of considerable precision. It should be used where no perceptible shake is permissible and where moving parts are not intended to move freely under a load.

Wringing Fit (Class 5)—Zero to Negative Allowance.—This is also known as a "tunking fit" and it is practically metal-to-metal. Assembly is usually selective and not interchangeable.

Tight Fit (Class 6)—Slight Negative Allowance.—Light pressure is required to assemble these fits, and the parts are more or less permanently assembled, such as the fixed ends of studs for gears, pulleys, rocker arms, etc. These fits are used for drive fits in thin sections or extremely long fits in other sections and also for shrink fits on very light sections. Used in automotive, ordnance and general machine manufacturing.

Medium Force Fit (Class 7)—Negative Allowance.—Considerable pressure is required to assemble these fits, and the parts are considered permanently assembled. These fits are used in fastening locomotive wheels, car wheels, armatures of dynamos and motors, and crank disks to their axles or shafts. They are also used for shrink fits on medium sections or long fits. These fits are the tightest which are recommended for cast-iron holes or external members as they stress cast iron to its elastic limit.

Heavy Force and Shrink Fit (Class 8)—Considerable Negative Allowance.—These fits are used for steel holes where the metal can be highly stressed without exceeding its elastic limit. These fits cause excessive stress for cast-iron holes. Shrink fits are used where heavy force fits are impractical, as on locomotive wheel tires, heavy crank disks of large engines, etc.

183. Example of Limit Dimensioning and Use of the ASA Tables.—

Suppose a 1″ shaft is designed to run with a class 1 fit. The *nominal size* is then 1″ and the *basic size* is 1.000″. The ASA Table, page 587, shows that the hole may vary from 0.000 to + 0.003 which is the *tolerance on the hole*. The tolerance applied to the basic size of 1.000 would give 1.000 as the minimum size of the hole and 1.003 as the maximum, Fig. 470.

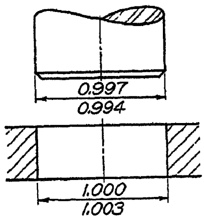


FIG. 470.—Clearance fit.

The table shows that the shaft may vary from −0.003 to −0.006. The actual *tolerance on the shaft* is the difference between these two minus values, or 0.003″. The two minus values applied to the basic size of 1.000 would give 0.997 as the maximum size of the shaft and 0.994 as the minimum.

From the definition of allowance the difference between maximum shaft (0.997) and minimum hole (1.000) would be 0.003. Note that the hole dimension has the minimum hole size above the dimension line, and the shaft dimension has the maximum shaft size above the dimension line. This is for convenience in machining. The difference between the two limits for hole and shaft that are above their respective dimension lines is the allowance.

In the foregoing example the fit is a "clearance" fit; that is, the shaft is to turn in the hole (bearing). When the shaft is to be permanently fixed in a hole (hub), an "interference" fit is necessary, with the shaft made larger than the hole. An example follows:

Nominal size 2″. Class 8 fit. Basic size 2.000. From the ASA Table, page 588:

Hole or External Member	Shaft or Internal Member
+0.0008 and 0.0000	+0.0028 and +0.0020

These values applied to the basic size give the limit dimensioning, Fig. 471.
Tolerance on hole: 2.0008 − 2.0000 = 0.0008
Tolerance on shaft: 2.0028 − 2.0020 = 0.0008
Allowance: 2.0028 − 2.0000 = 0.0028

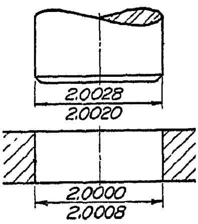
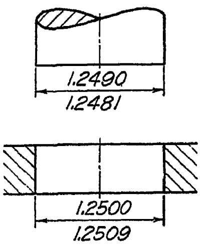


FIG. 471.—Interference fit.



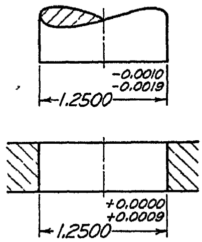


FIG. 472A. FIG. 472B.
Unilateral system, two methods.

184. Unilateral Tolerances.—The ASA system uses unilateral tolerances; that is, the tolerance is taken all plus or all minus from the basic size (see foregoing example).

In Fig. 472 the method shown at *A* is approved by the ASA and is the method recommended where gages are used, and on small parts. That at *B* is sometimes employed and is approved for large parts where gages are not used, but it requires the workman to add or subtract figures.

185. Bilateral System.—Another method known as "bilateral limits" is used to some extent though not recommended by the ASA. In this method the tolerance is divided so that half of it is above and half below the basic size. As an example, nominal size 2″, loose fit; total tolerance on hole and also on shaft, 0.001; allowance, 0.003.

For the hole the tolerance is applied to the basic size, and the dimension would be: 2.0000 ± 0.0005. The allowance is then subtracted from the basic size to get the "average size" of the shaft: 2.000 − 0.0030 = 1.9970.

The tolerance is then applied, and the dimension of the shaft is 1.9970 ± 0.0005, Fig. 473.

186. Tolerance on Centers.—In any case where centers are arranged for interchangeable assembly the tolerance on shaft, pins, etc., and also the tolerance on bearings or holes in the mating piece will affect the possible tolerance on centers. In Fig. 474 note that smaller tolerances on the pins and holes would necessitate a smaller tolerance on the center distances. A smaller allowance for the fit of the pins would make a tighter fit and reduce the possible tolerances for the center-to-center dimensions. Study carefully the dimensions of both pieces.

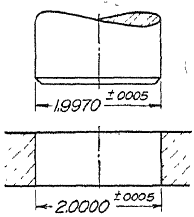


Fig. 473.—Bilateral system.

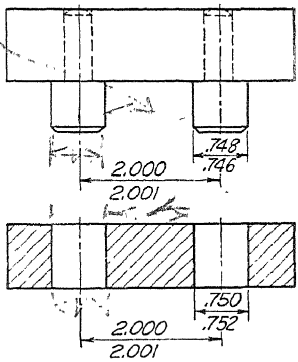


Fig. 474.—Tolerance on centers.

187. Tolerance for Angular Dimensions.—When it is necessary to give the accuracy required in an angular dimension the tolerance is generally bilateral, as 32° ± ½°. When the tolerance is given in minutes, it is written ±0°-10′, and when given in seconds is written ±0′-30″. Where the location of a hole or other feature is dependent upon an angular dimension, the length along the leg of the angle governs the angular tolerance permitted. A tolerance of ±1° gives a variation of 0.035 inch for a length of 1 inch, and may be used as a basis for computing the tolerance in any given problem.

As an example, assume an allowable variation of 0.007 inch; then (0.007/0.035) × 1° = ⅕° is the angular tolerance at 1 inch, and if the length is assumed as 2″ then the tolerance would be ½ the tolerance computed for 1 inch, or ⅕° × ½ = ⅒° or 0° -6′.

188. Tolerance for Concentricity.—Two geometrical surfaces are said to be concentric when their centers or axes coincide. Mating pairs of two (or more) closely fitting machined cylindrical surfaces must have the axes of adjoined cylinders nearly concentric in order to permit assembly of the parts; thus a method of giving the permissible deviation from concentricity is sometimes necessary. One method is to mark the dimensions with reference letters and give the tolerance in note form as at *A*, Fig. 475. The

reference letters may be dispensed with if the note is applied directly to the surfaces as at B. As an illustration of the method used in determining the permissible tolerance for concentricity, the dimensioning of the parts shown in Fig. 475, which are designed to work together, may be analyzed and studied. In this case the largest internal members mated with the smallest external members would present the most dangerous condition from the standpoint of assembly, and from the dimensions there would be 0.001″ clearance between the upper pair of cylinders and also 0.001″ clearance between the lower pair if the axes of the cylinders in part A and also in part B are *exactly concentric.*

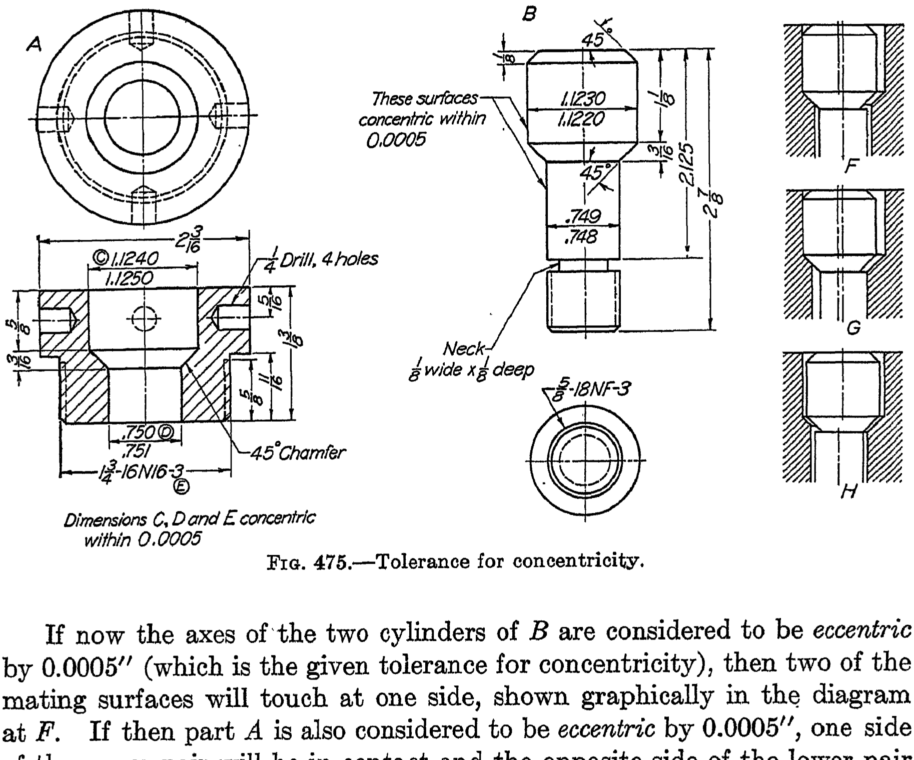


FIG. 475.—Tolerance for concentricity.

If now the axes of the two cylinders of B are considered to be *eccentric* by 0.0005″ (which is the given tolerance for concentricity), then two of the mating surfaces will touch at one side, shown graphically in the diagram at F. If then part A is also considered to be *eccentric* by 0.0005″, one side of the upper pair will be in contact and the opposite side of the lower pair will also be in contact, shown graphically at G. For this condition, where both pieces are considered to be eccentric by the maximum allowed in the tolerance for concentricity, note that the inner part could be rotated; that there would be contact of opposite sides as described at one position; and if one part is turned 180° from the first position, the same clearances as if the parts were all perfectly concentric would prevail. Study the dimensioning of both parts and note that any change in the limits of diameter would result in a necessary change in the tolerance for concentricity, to permit assembly of the parts.

189. In dimensioning with limits, experience in manufacturing is needed as well as a study of the particular mechanism involved before the draftsman is able to know just the accuracy necessary and can specify proper fits and tolerances. The following quotation from the ASA Standard is pertinent:

> In choosing the class of fit for manufacture, the engineer should keep in mind that cost usually increases proportionately to the accuracy required, and no finer class of fit should be chosen than the functional requirements actually demand. It is axiomatic that the closer the fit the smaller the manufacturing tolerance, and usually the greater the cost. The length of engagement of the fit also plays an important part in the selection of the class of fit for a piece of work. It is obvious that a long engagement will tolerate more looseness than a short one, and due regard should be paid to this feature.

190. Dimensioning Half Sections.—In general the half section is difficult to dimension clearly without some possibility of misleading, ambiguous or

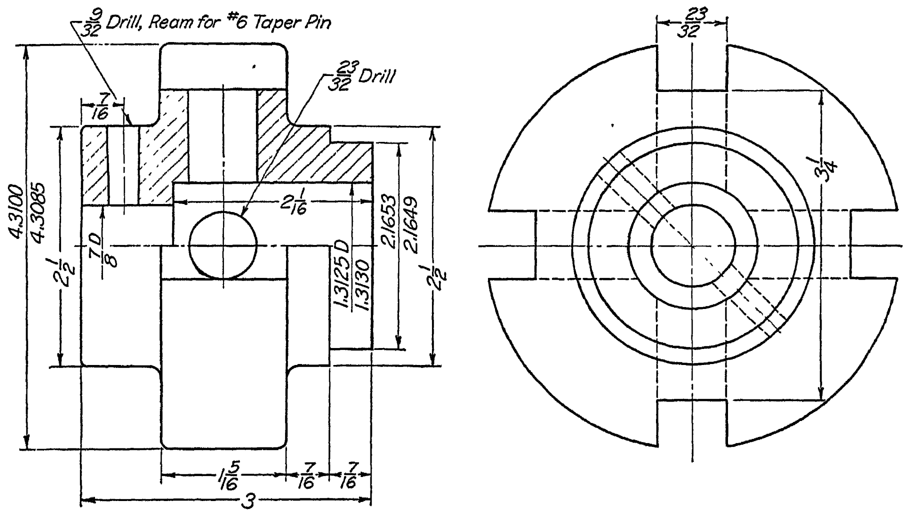


FIG. 476.—Dimensioning a half section (pintle block).

crowded information. Generous use of notes and careful placement of the dimension lines, leaders and figures will in most cases suffice to make the dimensioning clear, but because of the difficulty, the following may be stated with the force of a rule: *when the half section cannot be clearly dimensioned, use an extra view or part view to describe the size.*

Inside diameters, either nominal or limited, should be followed by the letter *D* and the dimension line carried over the center line to prevent the possibility of reading the dimension as a radius, Fig. 476. Generally, dimensions of internal parts should be placed inside the view to prevent confusion between extension lines and the outline of external portions.

191. Dimensions for the Pattern Shop.—Some engineering offices prepare for all castings a set of "pattern drawings" for the exclusive use of the

pattern shop, containing only the information needed by the patternmaker. Figure 477 shows a pattern drawing of a cut gear blank. Where the weight of the rough casting is a factor, as in production work, the allowances for

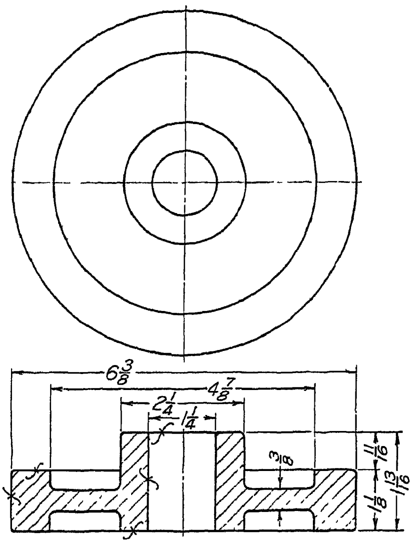


Fig. 477.—A pattern drawing.

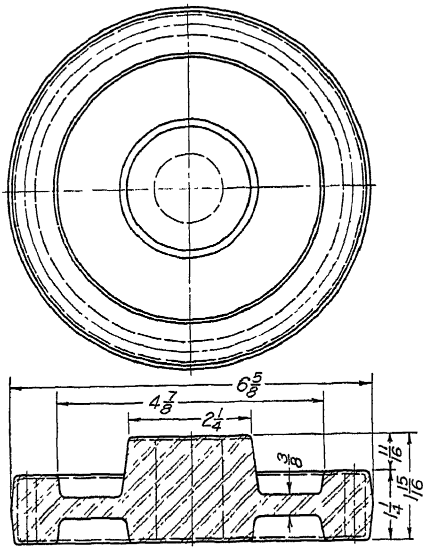


Fig. 478.—A forging drawing.

finish and draft are specified by the engineering department and included in the dimensions, in which case no finish marks are put on the drawing.

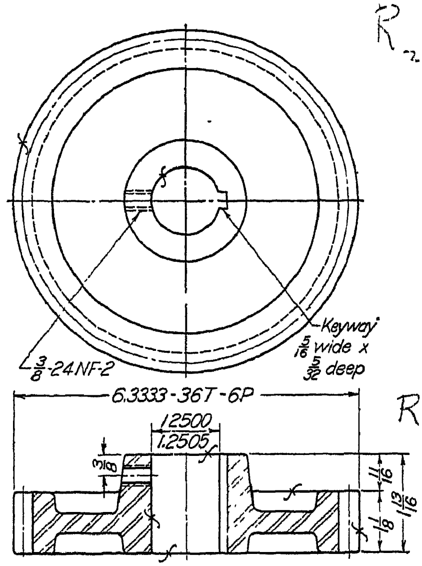


Fig. 479.—A machine-shop drawing.

192. Dimensions for the Forge Shop. Separate "forging drawings" are usually made when a piece is to be machined from a forging. These drawings are to scale (preferably full size) and show the completed forging in the stage ready for the machine shop, with all the dimensions needed by the forge shop. No dimensions for finish are given, but the outlines of the finished piece are shown in light dash-lines within the contour, as in Fig. 478.

193. Dimensions for the Machine Shop.—When separate drawings are made for the pattern shop or forge shop, the machine-shop drawing contains only the dimensions for machining the piece, as in Fig. 479. The separate-drawing system prevents congestion of the dimensions and consequently makes the drawings easier to work from. On the other hand, the single system has the advantage of giving all the

information about the piece on one sheet. Paragraphs 177 to 190 refer to machine-shop dimensioning.

194. Dimensions for the Assembly Shop.—This information, placed on the assembly drawing, identifies and locates the various parts so that the machine can be built from it. Sometimes a separate sheet called an "erection drawing" is made.

195. Dimensions for the Purchaser.—Before the delivery of a machine the purchaser needs some dimensional information, such as the method of mounting, size of foundation, and location of bolts; the floor space and clear height required with all moving parts in maximum positions; the required locations of source of power, rpm of driving pulleys, gears or motor; location of any piping or wiring; etc. These dimensions are given on a foundation

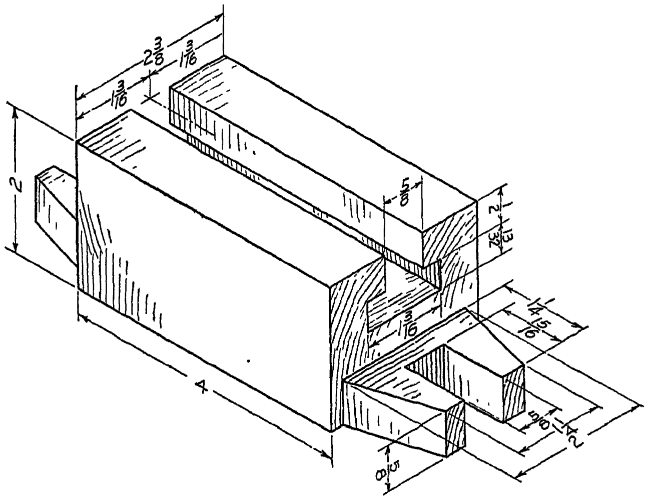
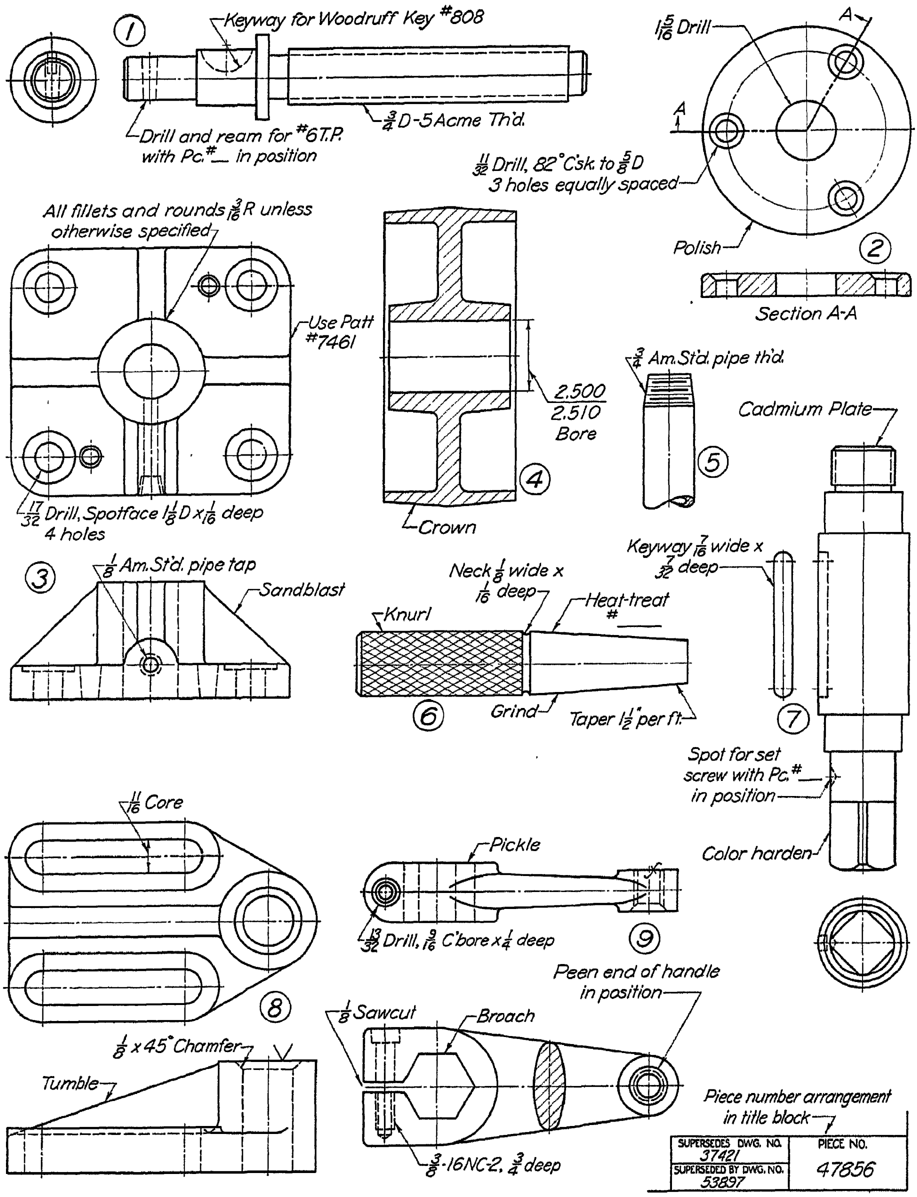


Fig. 480.—Dimensioning a pictorial drawing (anchor block).

plan or on an outline assembly drawing prepared for the customer's use. Sometimes the drawing of a template, to be built by the purchaser and used for setting foundation bolts, is sent.

196. Dimensioning Pictorial Drawings.—When isometric or other pictorial forms are used as working drawings the size description is often more difficult than the shape description. With the principles in this chapter as a basis, the general rule to follow is to have all the extension lines and dimension lines parallel to the axes and to have the figures so made that they appear to lie in the plane of the face containing the part dimensioned. To do this the figures should be pictorial drawings of **vertical** figures. Leaders and dimensions in note form will be necessary oftener than on orthographic drawings. Figure 480 illustrates the system.

197. Notes and Specifications.—Some necessary information cannot be drawn and hence must be added in the form of notes. This includes the number required of each piece, the kind of material, kind of finish, number



NOTE (appears on)	PC. No.	NOTE (appears on)	PC. No.	NOTE (appears on)	PC. No.	NOTE (appears on)	PC. No.
Bore	4	Fillet	3	Peen	9	Section	2
Broach	9	Finish	8 (new) 9 (old)	Pickle	9	Spot	7
Chamfer	8	Grind	6	Plate	3	Spotface	3
Core	8	Harden	7	Polish	2	Tap	3,9
Counterbore	9	Heat-treat	6	Ream	1	Taper	6
Countersink	2	Keyway	1,7	Rounds	3	Thread	1,5
Crown	4	Knurl	6	Sandblast	3	Tumble	8
Drill	1,2,3,9	Pattern	3	Sawcut	9	Turn	6

FIG. 481.—Approved wording for notes on drawings.

and kind of bolts and screws, and any other specifications as to construction or use. A note may be a single word on a leader pointing to the surface, or it may be a sentence lettered near the part to which it refers. Notes should be read horizontally on the sheet. General notes referring to the entire machine or to all drawings on one sheet are collected and lettered in one place.

Do not be afraid to put notes on drawings. Supplement the graphic language by the English language whenever added information can be conveyed, but be careful to word it so clearly that the meaning cannot possibly be misunderstood.

If a note as to the shape of a piece will save making a view without sacrificing clearness, use it. If, in detailing right- and left-hand pieces, different patterns are required, then both pieces should be drawn; if one pattern can be used (as should be done if possible) but machined right and left, both should be drawn; if identical but assembled right and left, one only is drawn and the number required noted. Standard bolts and screws, taper pins, washers, keys and nuts are not detailed when specified by note or in the bill of materials.

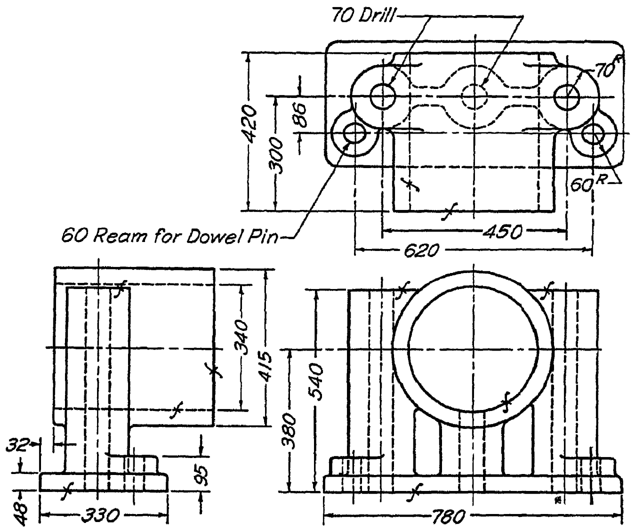


FIG. 482.—A metric drawing (front camshaft bearing, Hispano-Suiza aero-engine).

An approved form of wording for notes occurring more or less frequently on drawings is given in Fig. 481.

198. The Metric System.—Knowledge of the metric system will be of advantage as it will be encountered on drawings from countries where this system is the standard and with increasing frequency on drawings made in the United States. The first international standard of a mechanical device is that of ball bearings, which have been standardized in the metric system, except for sizes of balls.

Drawings in the metric system are not made to half size or quarter size. The first regular scale smaller than full size is one-fifth size, then one-tenth size. Sometimes the scale of 1 to 2½ is used. The unit of measurement on drawings is the millimeter (mm), and the figures are all understood to be millimeters, without any indicating marks. Figure 482 is an example

of metric dimensioning. A table of metric equivalents is given in the Appendix.

199. The Ford Decimal System.—Since 1932 the Ford Motor Company has been using a decimal system original with the company for dimensioning drawings and in manufacturing operations.

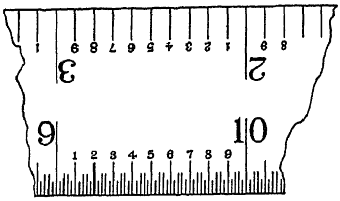


Fig. 483.—A Ford scale.

This system abandons the cumbersome common fractions of quarters, eighths, sixteenths, etc., and uses decimal divisions for all subdivisions of the inch. It thus secures one of the principal advantages claimed for the metric system, without the disadvantages which have prevented the universal adoption of that system.

In the engineering department and the various shops throughout the Ford plants, all scales marked in common fractions were replaced by scales based on tenths of an inch, which, to facilitate reading, have the smallest divisions in fiftieths instead of hundredths. Figure 483 shows a portion of one of the scales used. All distances formerly designed and dimensioned

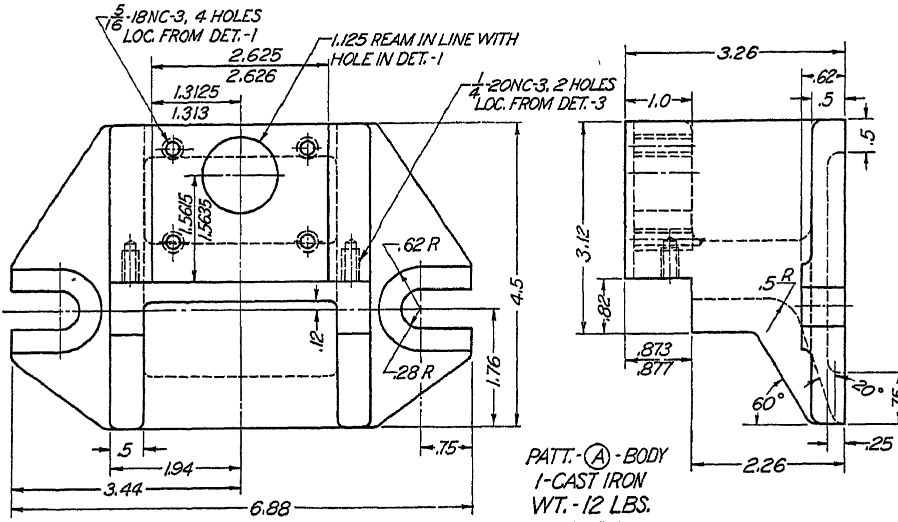


Fig. 484.—A Ford drawing (jig body).

with sufficient accuracy in common fractions are given to one place, as 3.5, 2.6. Where greater accuracy is required the second place is added, but always in multiples of 2, as 3.56, 2.62, so as to be readable to the eye. For more accurate measurements, using the micrometer and for setting limits, it becomes only a matter of adding additional digits to an already existing decimal. The advantage in calculating, adding and checking and in doing away with all conversion tables, as well as in lessening chances of error, is apparent.

Figure 484, illustrating the system, is from a Ford drawing of a jig body. It is suggested that one or two problems such as those of Figs. 592 to 600 be redesigned for decimal dimensioning under this system.

PROBLEMS

200. The problems following are given as preliminary studies in dimensioning, on which to apply the principles of this chapter. Attention should be given to the methods of machining as explained in Chap. X, and the machining operations given in note form, when possible. Locate holes, etc., from center lines or a finished surface to which they are related. Every working drawing is, of course, a dimensioning problem.

Group I. Pieces to Be Drawn and Dimensioned.

The illustrations are either half or quarter size. Draw them full size, scaling or transferring dimensions with dividers, and add all dimensions necessary for the construction. Assume and mark finished surfaces.

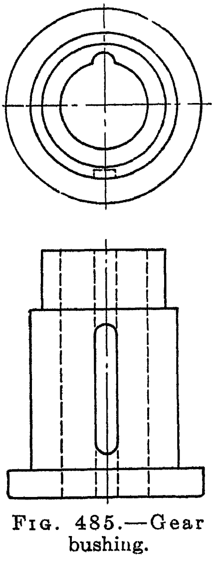


FIG. 485.—Gear bushing.

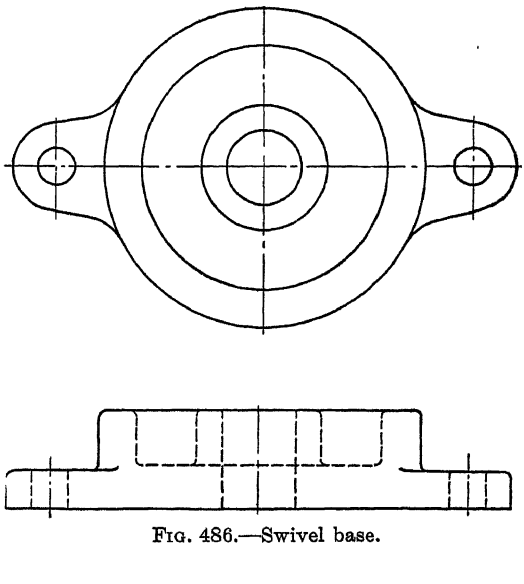


FIG. 486.—Swivel base.

1. Fig. 485. Compound gear bushing, used in feed gearing. Cast iron; finished all over.

2. Fig. 486. Swivel base, for angular adjustment. Bakelite die-casting.

3. Fig. 487. Shaft bracket; cast iron. Base slot and front end of hub finished. Hole in hub is bored; hole in base is drilled and counterbored.

4. Fig. 488. Pivot block; cast iron, slots cored, all contact surfaces finished.

5. Fig. 489. Sliding support; cast steel. Finished surfaces are indicated by ASA finish mark. Add surface roughness symbols.

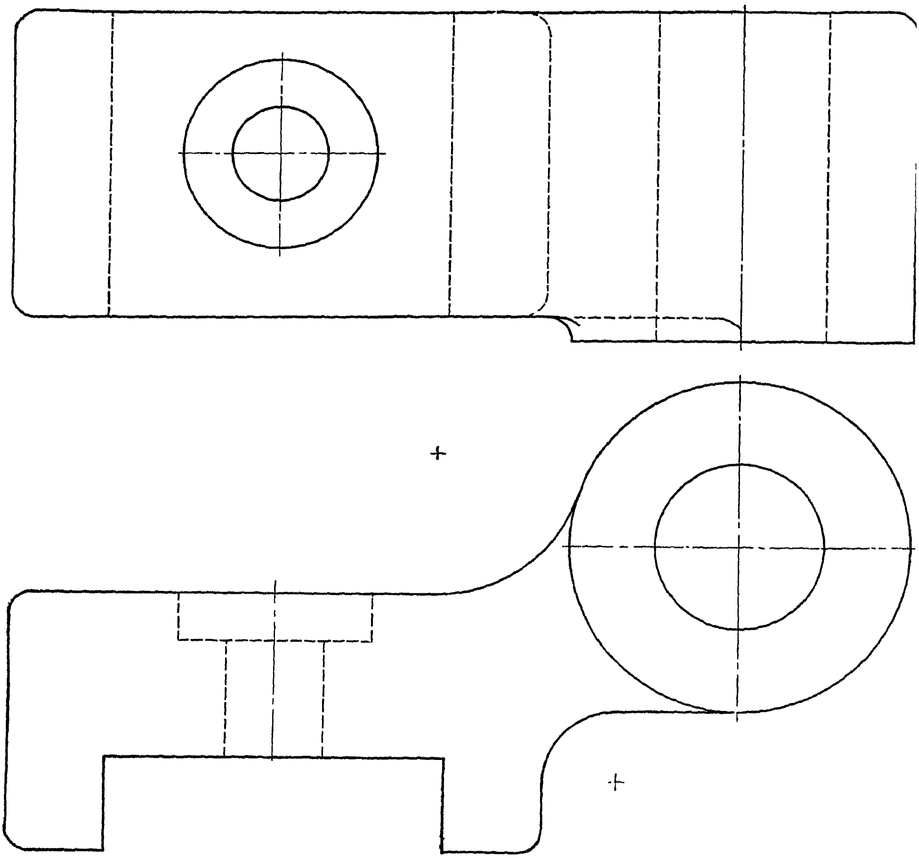


FIG. 487.—Shaft bracket

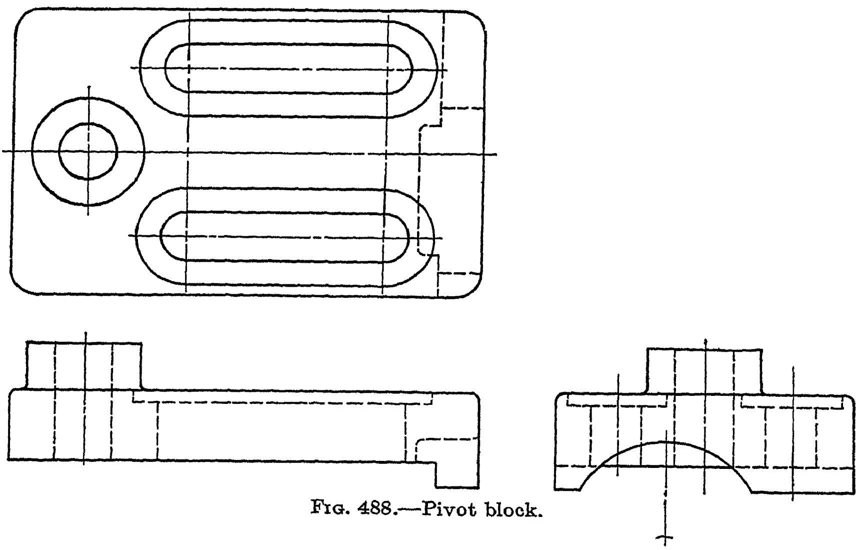


FIG. 488.—Pivot block.

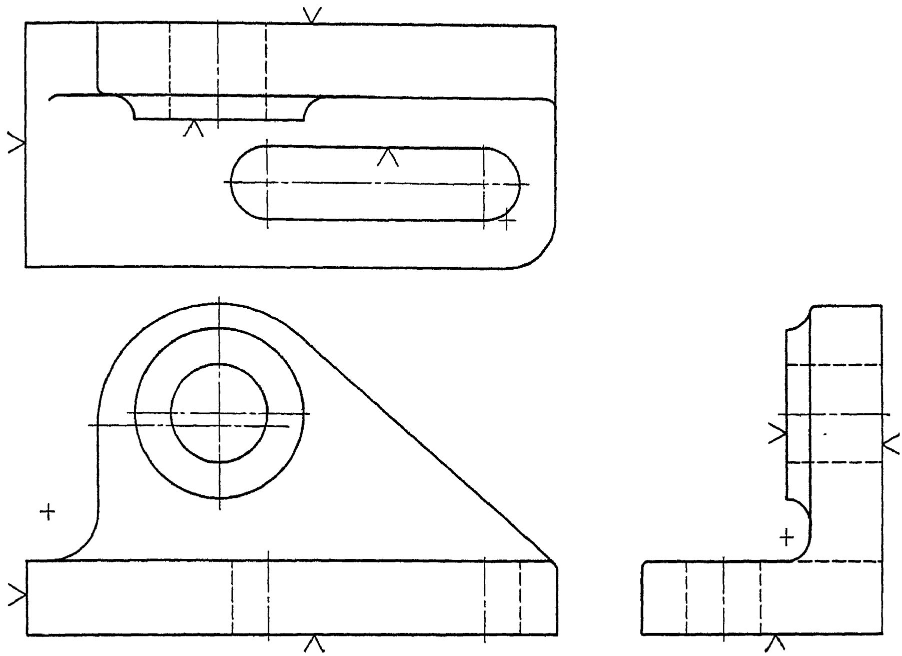


FIG. 489.—Sliding support.

Group II. Dimensioned Drawings from Models.

An excellent exercise in dimensioning is to make a detail drawing from a pattern, casting or forging, or a model made for the purpose. Old or obsolete patterns can often be obtained from companies manufacturing a variety of small parts, and "throw-out" castings or forgings are occasionally available. Familiarity with the methods of measuring is essential, as explained in Chap. XVIII. In taking measurements from a pattern a shrink rule should always be used, and allowance must be made for finished surfaces.

Group III. Dimensioned Drawings from Pictorial Views.

The problems presented in pictorial form in Chaps. VII, VIII and IX may be used as dimensioning problems, either dimensioning one already drawn as an exercise in shape description or, for variety, one not previously made. A selection of twelve problems, graded in order of difficulty, is given below.

6. Fig. 245. Step block. No finished surfaces.
7. Fig. 248. Slotted wedge. Slot and base finished.
8. Fig. 257. Corner stop. Slot at top, cut corner and base finished.
9. Fig. 260. Guide base. Vertical slot, boss on front, and base finished.
10. Fig. 262. Eccentric. Finished all over.
11. Fig. 267. Brake shoe. Ends of hub and braking surface finished.
12. Fig. 277. Shifter fork. All contact surfaces finished.
13. Fig. 279. Shaft guide. L-shaped pad and end of hub finished.
14. Fig. 345. Jig angle. Finished all over.
15. Fig. 348. Angle shaft base. Base and slanting surface finished.
16. Fig. 353. Radial swing block. All contact surfaces finished.
17. Fig. 360. Transverse connection. Base pads finished.

Group IV. Sketching Problems.

18, 19, 20, 21. Figs. 490 to 493. From pictorial sketches given make freehand orthographic sketches, and by adding dimension lines with arrowheads, show the placement of all dimensions according to the rules for dimensioning. Instead of dimension figures use the letter S to indicate size dimensions and L to indicate location dimensions.

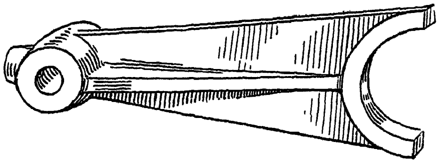


FIG. 490.—Countershaft shifter fork.

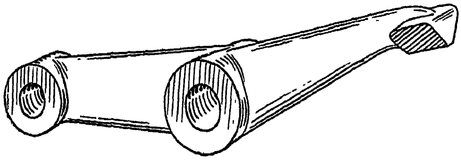


FIG. 491.—Interlocking lever.

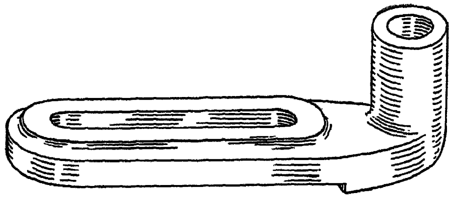


FIG. 492.—Indexing crank.

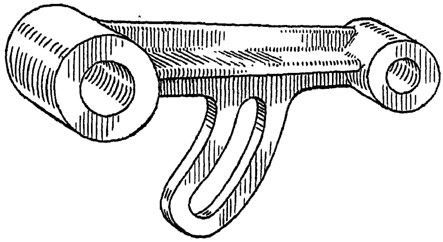


FIG. 493.—Adjustable arm.

CHAPTER XII

BOLTS, SCREWS, KEYS, RIVETS AND SPRINGS

201. In the practical application of the graphic language in making working drawings there occurs the necessity of representing the methods of fastening parts together, either with permanent fastenings, as rivets and welding, or with removable ones, as bolts, screws and keys. The engineer must know the fundamental forms of these fastening parts and be thoroughly familiar with the conventional method of their representation.

202. The origin of the screw is unknown. It does not appear either in the thousands of artifacts, or in the paintings, from Egyptian tombs. Not one has been found in ancient Babylon, Crete or Troy, and it is not mentioned by Homer or other early Greek writers. The earliest records of the screw are found in the writings of Archimedes (278–212 B.C.), although specimens of ancient Greek and Roman screws are so rare as to indicate that they were seldom used. But in the later Middle Ages many are found, and it is known that both lathes and dies were used to cut threads. However, most early screws were made by hand, forging the head, cutting the slot with a saw and fashioning the screw with a file. In colonial times, wood screws were blunt on the end, the gimlet point not appearing until 1846. Iron screws were made for each tapped hole. There was no interchanging of parts, and nuts had to be tied to their own bolts. Sir Joseph Whitworth made the first attempt at a uniform standard in 1841. This was generally adopted in England but not in the United States.

203. The initial attempt to standardize screw threads in the United States came in 1864 with the adoption of a report prepared by a committee appointed by the Franklin Institute. This system, designed by William Sellers, came into general use and was known as the "Franklin Institute thread," the "Sellers thread" or the "United States thread." It fulfilled the need of that period, but with the coming of the automobile, the airplane and other modern equipment it was not adequate. Through the efforts of the various engineering societies, the Bureau of Standards and others, the National Screw Thread Commission was authorized by Act of Congress in 1918 and inaugurated the present standards. This work has been carried on by the American Standards Association, 29 West 39th Street, New York City, from whom complete copies of the Standards may be obtained. The essential items appear in this chapter and in the Appendix.

204. The Helix.—The helix is a space curve generated by a point moving uniformly along a straight line while the line revolves uniformly about

another line as an axis. If the moving line is parallel to the axis it will generate a cylinder, and the word "helix" alone always means a cylindrical helix. If the moving line intersects the axis at an angle less than 90° it will generate a cone, and the curve made by the point moving on it will be a "conical helix." The distance parallel to the axis through which the point advances in one revolution is called the "lead." When the angle becomes 90° the helix degenerates into the Archimedean spiral.

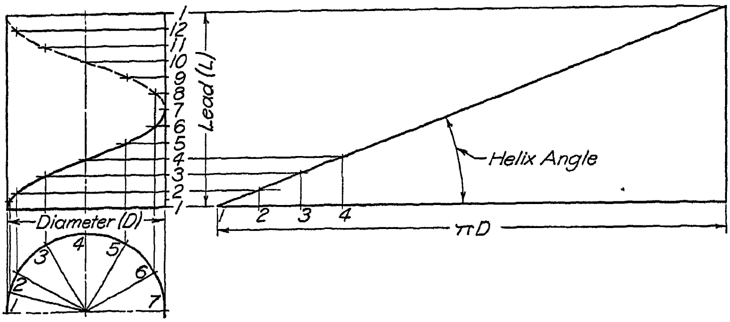


Fig. 494.—The helix and its development.

To Draw a Helix.—Fig. 494. Draw the two views of the cylinder and measure the lead along one of the contour elements. Divide this lead into a number of equal parts, (say 12) and the circle of the top view into the same number. Number the divisions on the front view, starting at point 1, and the divisions on the top view, starting at the top view of point 1. When the generating point has moved one-twelfth of the distance around the cylinder it has also advanced one-twelfth of the lead; when halfway round the cylinder it will have advanced one-half the lead. Thus points on the front view of the helix may be found by projecting the top views of the elements, which are points on the circular top view of the helix, to intersect lines drawn across from the corresponding divisions of the lead. The conical helix is drawn similarly, the lead being measured along the axis. If the cylinder is developed, the helix will appear on the development as a straight line inclined to the base at an angle, called the "helix angle," whose tangent is $L/(\pi D)$ where L is the lead and D the diameter.

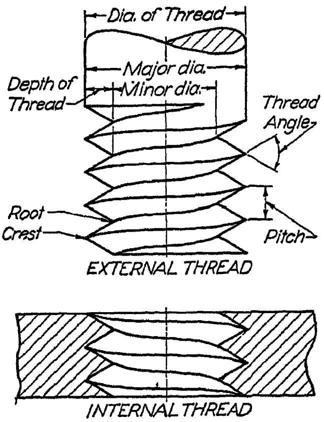


Fig. 495.—Screw-thread terminology.

205. Screw-thread Terminology.—Fig. 495. *External thread*—A thread on the outside of a member. *Internal thread*—A thread on the inside of a member. *Major diameter*—The largest diameter of a screw thread. *Minor diameter*—The smallest diameter of a screw thread. *Pitch*—The distance

between corresponding points on consecutive threads measured parallel to the axis. *Lead*—The distance, parallel to the axis, that the screw advances in one complete revolution. (See multiple threads, Fig. 496.) *Crest*—The top surface joining the two sides of a thread. *Root*—The bottom surface joining the sides of two adjacent threads. *Depth of thread*—The distance between crest and root measured normal to the axis. *Right-hand thread*—A thread that advances into engagement when turned clockwise. *Left-hand thread*—A thread that advances into engagement when turned counterclockwise. It can be distinguished from a right-hand thread by the opposite direction of its slant. *Single thread*—A single thread has one thread of whatever section cut on the cylinder. Threads are always understood to be single and right-hand unless otherwise specified. *Multiple threads*—To obtain a more rapid advance without using a coarser thread, two or more threads are cut side by side, giving double, triple, etc., threads, as illustrated in Fig. 496. On a single thread the lead and pitch are equal. On a double

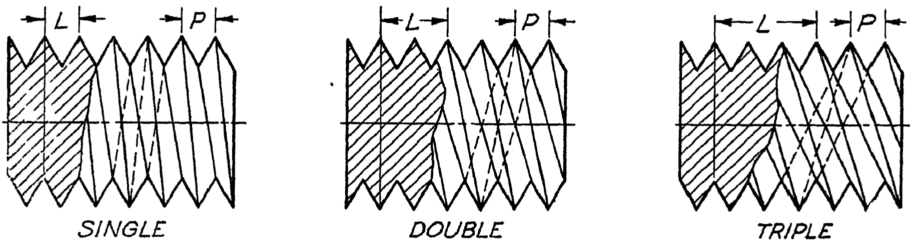


FIG. 496.—Single, double and triple threads.

thread the lead is twice the pitch and on a triple thread it is three times the pitch. Note that the threads of a double thread start at 180° apart; those of a triple thread 120° apart. Fountain-pen caps often have quadruple threads, so that with a minimum of turning the cap is securely fastened to the barrel.

206. Forms of Screw Threads.—Screws are used for fastenings, for adjustments and for transmitting power and motion. For these different purposes several different forms of threads are in use, Fig. 497. For fastenings, the *American Standard V-thread*, with its crest and root flattened, is used in this country. The American Standard is discussed in detail in a following paragraph. The sharp V at 60° is still used to some extent although it has little to recommend it, except the increased holding power for setscrews and perhaps a better liquidtight joint such as on stay bolts for boilers. It is often used on brass fittings and brass pipe as well as in modified form on self-tapping screws. The British Standard is the *Whitworth* thread, cut at 55°, with tops and bottoms rounded one-sixth of the depth of the triangle, as shown in the figure. *The British Association Standard* at 47½° is used on very small threads. *The French and the International Standards* have the same form as the American Standard but are dimensioned in the metric system. The *Dardelet self-locking* thread, designed by Com-

mandant Dardelet, a French military officer, is a special thread requiring no auxiliary locking devices to hold the nut under vibration. A more complete description is found in paragraph 227.

For transmitting power the V-shapes are not desirable since part of the thrust tends to burst the nut. The square thread avoids this as it transmits all the forces nearly parallel to the axis of the screw. It can have, evidently, only half the number of threads in the same axial space as a V-thread of the same pitch, and thus in shear is only half as strong. A modification used very generally is the *Acme* or 29° thread. It is stronger, much more easily

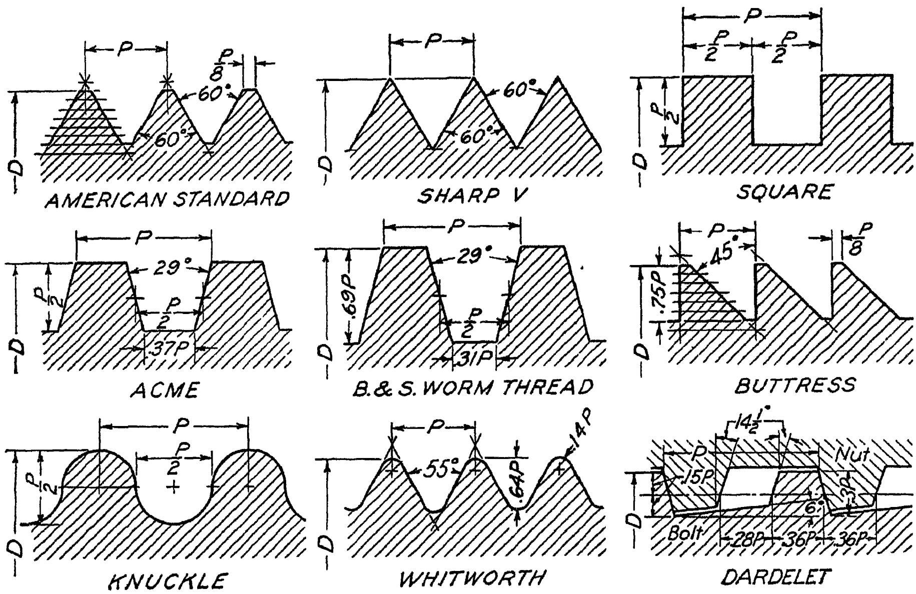


FIG. 497.—Thread profiles.

cut and permits the use of a disengaging or split nut, that cannot be used on a square thread. The *Brown and Sharpe* worm thread used on the worm of the worm-and-wheel mechanism resembles the Acme thread but is deeper for the same pitch. The *buttress* thread for transmitting power in only one direction has the efficiency of the square thread and the strength of the V-thread. It is sometimes called the breechblock thread, as it is used to take the recoil in guns. The *knuckle* thread is used for rough work and can be cast in a mold. It may be seen in shallower forms in sheet-metal rolled threads, as on an ordinary incandescent lamp.

Screw threads are formed by cutting or rolling. Laboratory tests show as much as 14 per cent greater strength in rolled threads over cut threads of the same diameter. By crimping the fibers in the metal, rolling adds toughness and strength to the threaded portion. A rolled thread fastening requires a collar under the head to bring the shaft diameter up to the thread diameter.

207. To draw a screw thread we must know the form of the thread, the diameter of the shaft on which it is cut, the number of threads per inch, whether it is single or multiple and whether it is right- or left-hand. For true representation the thread shapes can be drawn with the lines of their crests and roots shown as the projections of helices having the same pitch

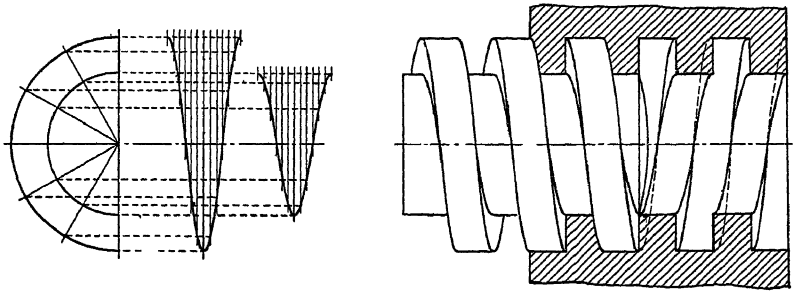


FIG. 498.—Square thread, external and internal.

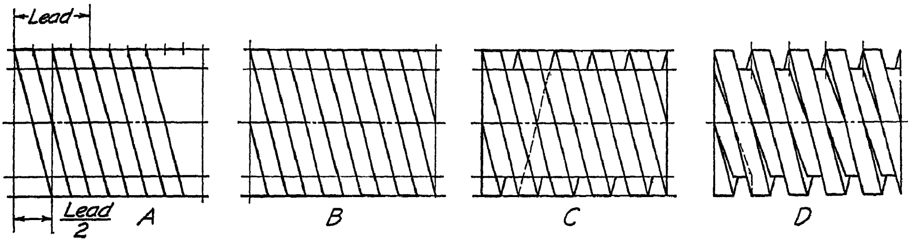


FIG. 499.—Stages in drawing a square thread.

but different diameters, as illustrated in Fig. 498. If many threads are to be drawn in this way, a template may be made by laying out the projection of the helices on cardboard, celluloid or thin wood and cutting out with a

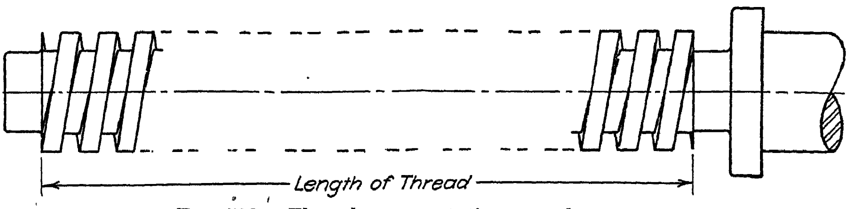


FIG. 500.—Thread representation on a long screw.

sharp knife. This drawing of the actual curves of a screw is a laborious proceeding and is rarely done, and then only on screws of large diameters. In ordinary practice the labor is altogether unnecessary, so the projection of the helix is conventionalized into a straight line.

208. Conventional Threads.—A double square-thread screw would thus be drawn as shown in stages in Fig. 499. This, although not so realistic or pleasing as Fig. 498, requires much less time. It is not necessary to draw the threads on the whole length of a long screw. They may be started at each end as in Fig. 500.

In the Acme thread the 29° angle may for convenience be drawn at 30°. The stages in drawing an Acme thread are shown in Fig. 501.

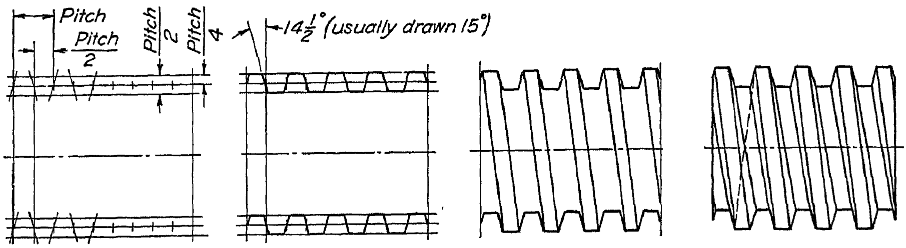


FIG. 501.—Stages in drawing an Acme thread.

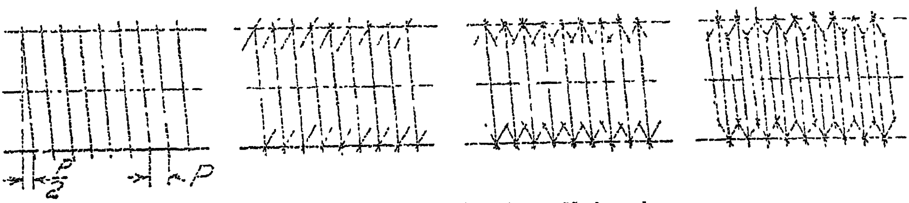


FIG. 502.—Stages in drawing a V-thread.

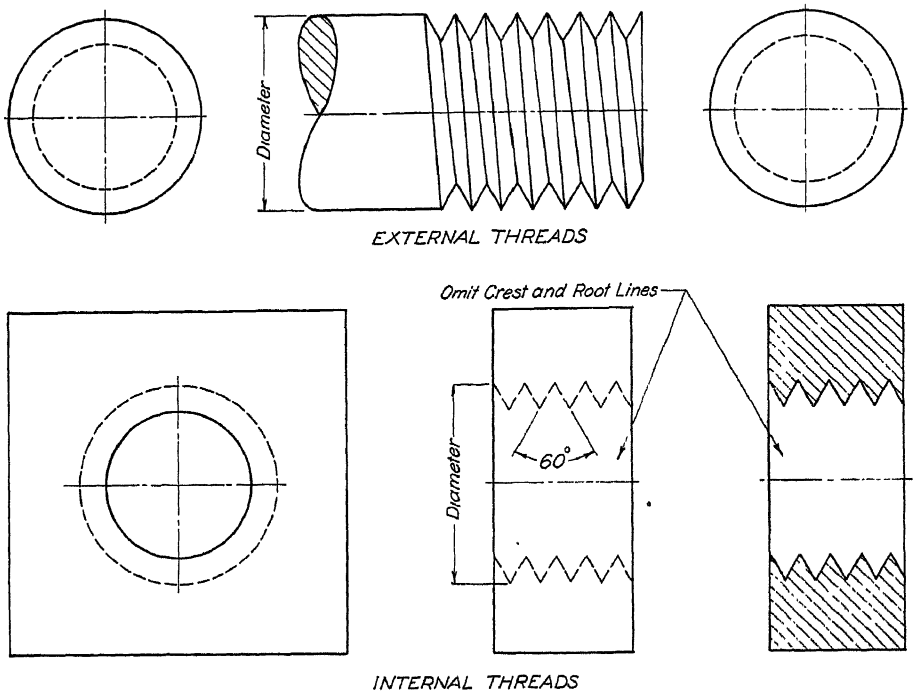


FIG. 503.—Thread representation (suggested for threads drawn 1 inch or over).

A V-thread is drawn in the stages shown in Fig. 502, spacing the pitch on the lower line only. It should be inked in the same order. The flats of crests and roots are not drawn.

It is suggested that threads of one inch and over in actual measurement, on both detail and assembly drawings, should show the thread form as in Fig. 502. In general true pitch should be shown, though a small increase or decrease in pitch is permissible so as to have even units of measure in making the drawing. For example, seven threads per inch may be increased to eight threads per inch, or four and one-half threads per inch may be decreased to four threads per inch. The student must keep in mind that

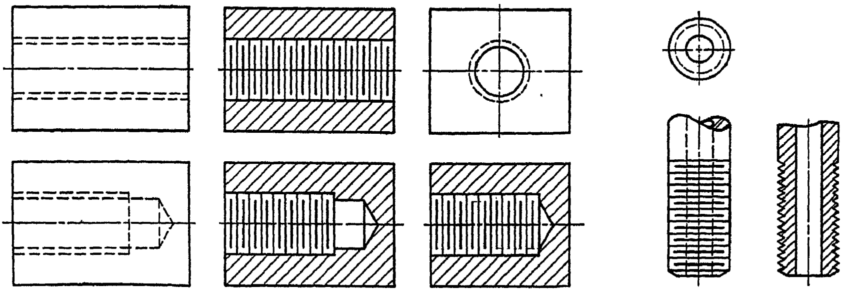


FIG. 504.—Regular thread symbols, ASA.

this is to simplify the drawing and that actual pitch must be specified in the dimensioning. Examples of these treatments are shown in Fig. 503.

Conventional threads ½″ and under 1″ in diameter (full size).—The ASA provides two forms of thread symbols: "regular" and "simplified." It is recommended that these symbols be limited to diameters less than one inch (full size), and also that the regular symbols be used on assembly drawings and simplified symbols on detail drawings.

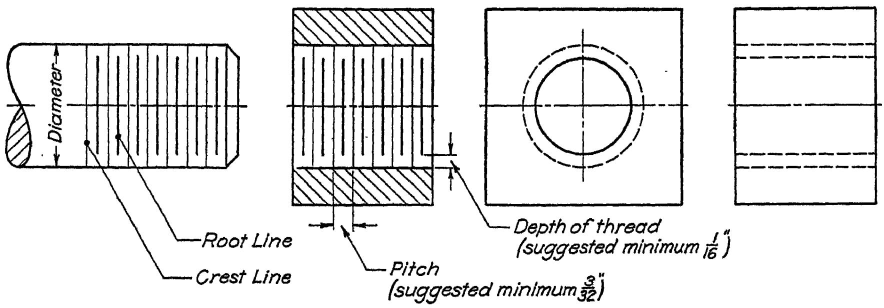


FIG. 505.—Regular thread symbols (proportions for threads drawn ½ inch to 1 inch).

209. ASA Regular Thread Symbols.—Fig. 504. This symbol omits the V profile and indicates crests and roots by lines perpendicular to the axis. The lines representing the crests are spaced by scale or eye to look well. A slight increase or decrease of actual pitch may be desirable for ease of drawing. The lines representing the roots of threads are equally spaced by eye between the crest lines, and are usually drawn heavier, Fig. 505. Their

length does not need to conform to the actual depth of the thread but should be kept uniform by using light guide lines.

210. ASA Simplified Thread Symbols.—Fig. 506. The simplified symbol omits both profile and cross lines, indicating the threaded portion by lines made of short dashes drawn parallel to the axis at the approximate depth of the thread. It does not have the descriptive effect of the regular symbol, but as it saves so much time it is preferred on detail drawings. It

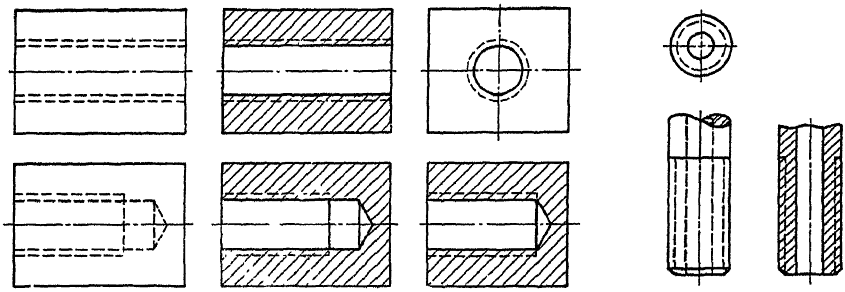


FIG. 506.—Simplified thread symbols, ASA.

is not recommended for assembly drawings or for internal sections. Note that the regular and simplified symbols for hidden threads are identical.

Figure 507 shows smaller threads drawn full size in both regular and simplified symbols, indicating that in order to avoid crowding, pitch and depth of thread values become coarser in proportion as the diameters decrease. Little if any distinction is made in the symbol between coarse and fine threads.

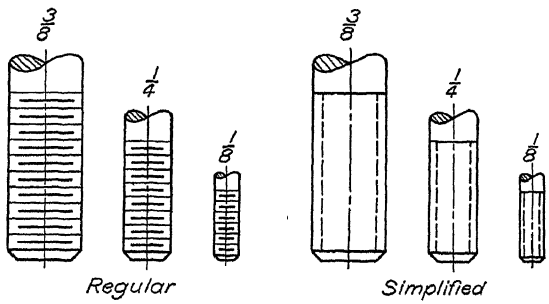


FIG. 507.—Symbols applied on small screws.

211. Threads in Section.—Figure 498 shows the true form of an internal square thread in section. Observe that the far side of the thread is visible, causing the root and crest line to slope in the opposite direction from those on the external thread. Figure 503 shows the treatment for V-threads over 1″ in diameter. Note that the crest and root lines are omitted. The regular and simplified symbols for threads in section are shown in Figs. 504 and 506. When two pieces screwed together are shown in section, the

thread form should be drawn to aid in reading, Fig. 508. In the small diameters it is desirable to decrease the number of threads per inch, thus eliminating monotonous detail and greatly improving the readability of the drawing.

212. American (National) Screw Threads.—The form of the American Standard is a 60° V-shape with the crest flattened to a width equal to one-eighth of the pitch and with the root filled in a like amount. This form was previously known as the "United States Standard" or "Sellers Profile."

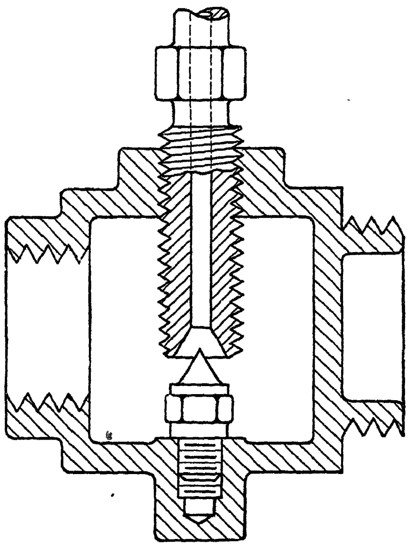


FIG. 508.—Threads in section (full size).

The American Standard covers five series of screw threads, all of the same thread form but differing in the relation of pitch to diameter. These are the Coarse Thread Series, the Fine Thread Series, and three special series —the 8-pitch, the 12-pitch and the 16-pitch Series.

The Coarse Thread Series is the former U. S. Std. supplemented by 12 numbered sizes below ¼ inch from the ASME Standards. It is the series recommended for general use. See table, page 573, Appendix.

The Fine Thread Series is the former Regular Series of the Society of Automotive Engineers supplemented by 13 numbered sizes below ¼ inch from the ASME Standards. It is used where special conditions require a fine thread. See table, page 573.

The 8-pitch Thread Series.—Eight threads per inch. Sizes 1″ to 6″.

Bolts for high-pressure pipe flanges, cylinder-head studs, and similar fastenings against pressure require that an initial tension be set up in the fastening by elastic deformation of the fastening and the component held together so that the joint will not open when the steam or other pressure is applied. To secure a proper initial tension it is not practicable that the pitch should increase with the diameter of the thread as the torque required to assemble the fastening would be excessive. Accordingly, for such purposes the 8-pitch thread has come into general use for all classes of engineering work. (See table, page 573.)

The 12-pitch Thread Series.—Twelve threads per inch. Sizes ½″ to 6″.

Sizes of 12-pitch threads from ½ to 1¾ inches in diameter are used in boiler practice, which requires that worn stud holes be retapped with the next larger size. Twelve-pitch threads are also widely used in machine construction for thin nuts on shafts and sleeves. See table, page 573.

The 16-pitch Thread Series.—Sixteen threads per inch. Sizes ¾″ to 4″.

This is a uniform pitch series used primarily on threaded adjusting collars and bearing retaining nuts. See table, page 573.

SAE Extra-fine Thread Series.—In addition to the five series provided by the ASA, the SAE (Society of Automotive Engineers) uses another series called the "Extra-fine Series."

The form and identification symbols follow those used by the American Standards. The only difference is the number of threads per inch. The SAE Extra-fine Series has more threads per inch than any series in the American Standards.

213. Classification of Fits.—One of the important features of the work of the Committee on Standardization and Unification of Screw Threads

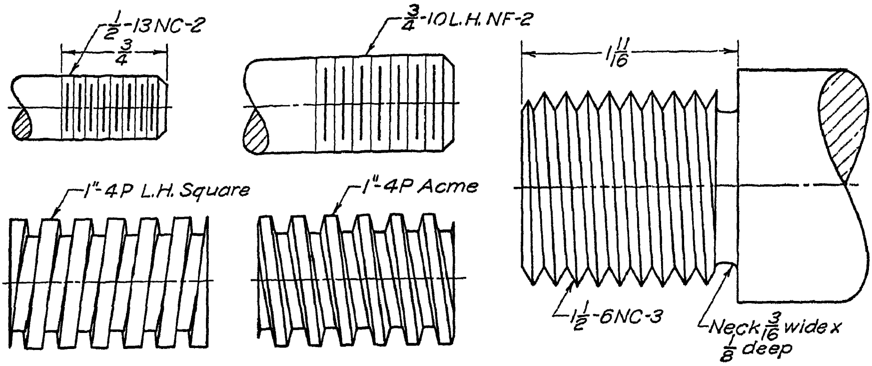


FIG. 509.—External thread specification.

(ASA B1a 1934) is in the standardizing of classes of fits between bolts and nuts. Four classes are provided, with detailed tables of dimensions and tolerances for manufacture to meet these classifications. These are:

Class 1 *Fit.*—This is "recommended only for screw thread work where clearance between mating parts is essential for rapid assembly and where shake or play is not objectionable."

Class 2 *Fit.*—This "represents a high quality of commercial screw thread product and is recommended for the great bulk of interchangeable screw thread work."

Class 3 *Fit.*—This "represents an exceptionally high quality of commercially threaded product and is recommended only in cases where the high cost of precision tools and continual checking is warranted."

Class 4 *Fit.*—This requires "selective assembly," there being an actual interference between a maximum screw and a minimum hole. It is "frankly experimental and it is still an open question whether or not it can be produced commercially."

214. Identification Symbols.—For specifying American (National) Standard threads on drawings, in correspondence, specifications, stock lists,

etc., the diameter (or screw number) and number of threads per inch are given first, then the initial letters of the series, NC (National Coarse), NF (National Fine) or N (National Form but special pitch), followed by the class of fit. If the thread is left-hand the letters L.H. follow the number of threads. Fig. 509.

Examples:

1″-8 NC-2
1″-14 L.H. NF-3
2″-8 N8-2
2″-12 N12-3
2″-16 N16-3
3¾-10 N-2

215. Tapped Holes.—Always specify by note, giving the tap-drill diameter and depth of hole, followed by the thread specification and length

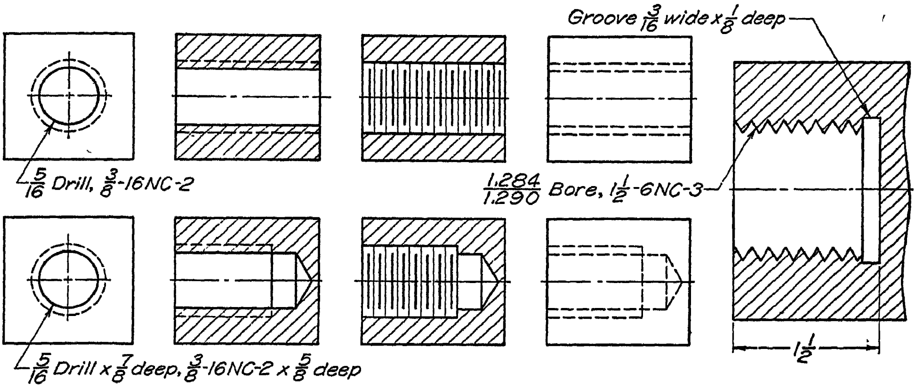


Fig. 510.—Internal thread specification.

of thread, Fig. 510. For tap-drill sizes see Appendix. It is general commercial practice to use 75 per cent of the theoretical depth of thread for

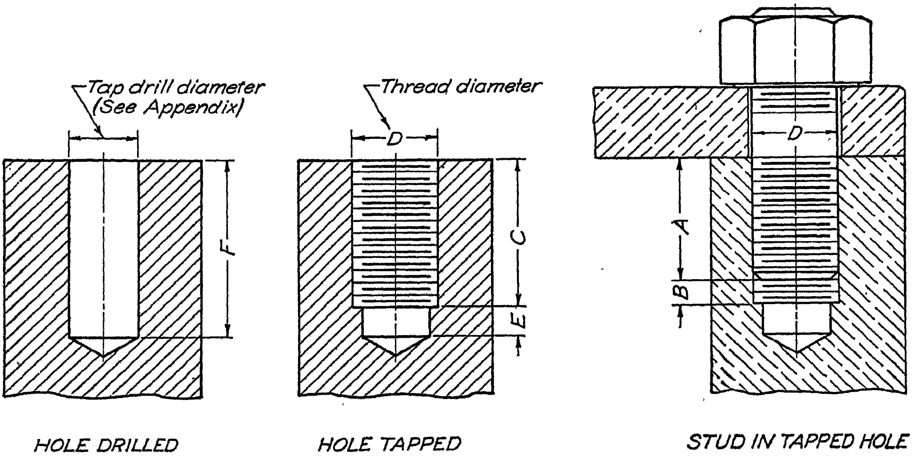


Fig. 511.—Proportions for tapped holes.

tapped holes. This gives about 95 per cent of the strength of a full thread and is much easier to cut. A bolt inserted in an experimental nut made with only one-half a full depth of thread will break before the thread will strip.

216. Depth of tapped holes and entrance length for threaded rods, tap bolts, studs, cap screws, machine screws and similar fastenings may be found by using an empirical formula based on the diameter of the fastening and the material tapped (see Fig. 511 and accompanying table).

Material	Entrance length for studs, etc., A	Thread clearance at bottom of hole, B	Thread length, C	Unthreaded portion at bottom of hole, E	Depth of drilled hole, F
Aluminum......	$2D$	¼″	$2D + \frac{1}{4}$	$4/n$	$C + E$
Cast iron.......	$1\frac{1}{2}D$	¼″	$1\frac{1}{2}D + \frac{1}{4}''$	$4/n$	$C + E$
Brass..........	$1\frac{1}{2}D$	¼″	$1\frac{1}{2}D + \frac{1}{4}''$	$4/n$	$C + E$
Bronze.........	$1\frac{1}{2}D$	¼″	$1\frac{1}{2}D + \frac{1}{4}''$	$4/n$	$C + E$
Steel...........	D	¼″	$D + \frac{1}{4}''$	$4/n$	$C + E$

D = diameter of fastening.
A = entrance length for fastening.
B = thread clearance at bottom of hole.
C = total thread length.
E = unthreaded portion at bottom of hole = $4/n$.
n = threads per inch.
F = depth of tap-drill hole.

217. Bolts.—Of the many forms of fastenings, the bolt, illustrated in pictorial form in Fig. 512, occurs most frequently. This familiar fastening

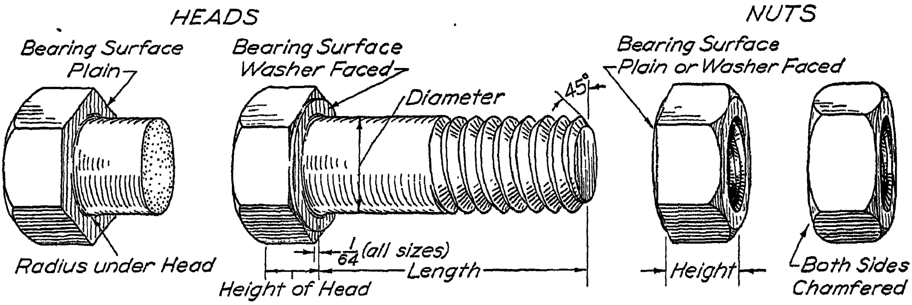


Fig. 512.—American Standard bolt.

is used, with a nut, to hold two pieces together by passing through clear holes in each. The body is a cold-drawn mild steel. The head may be completely formed by a series of upsetting and shearing operations, or a combination of upsetting, shearing and machining, to secure a desired finish. The threads are either cut or rolled. The nuts are sheared from

hexagonal bars and forged into shape, the holes punched and the threads tapped on automatic machines. Another method of manufacture is to machine the bolts and the nuts from hexagonal bars.

218. Bolt Information.—The draftsman must be thoroughly familiar with the following items concerning bolts and nuts:

General. *Diameter.*—The size of the shaft on which the threads are cut.

Body Length.—The distance from under the head to the extreme end. Length increments vary with the diameter. See Appendix. The thread end is flat and chamfered. The angle of chamfer is drawn 45° and the depth of chamfer is to the root of the thread.

Thread Length.—This depends on the diameter, and the length of the bolt. See Appendix. The thread lengths shown in this table are not a part of the standard but show the usual practice followed by manufacturers when American Standards bolts are ordered and apply to both regular and heavy series.

Radius of Fillet under Head.—The maximum radius for bolts 1/4" to 1/2" is 1/32"; for bolts 9/16" to 1" is 1/16"; for bolts 1 1/8" to 2" is 1/8"; for bolts 2 1/4" to 3" is 3/16". In general the filleted corner may be accommodated to the bolt hole by burring the rim of the hole and may be omitted on the drawing except in very large sizes.

Washer Face.—The washer face is a circular base, turned or otherwise formed on the bearing surface of a bolthead or nut, to make a smooth bearing surface. The diameter is equal to the distance across flats. The thickness is 1/64" for all fastenings. A circular bearing surface may be obtained on a nut by chamfering the corners. The angle of chamfer with the bearing face is 30°, and the diameter of the circle is the width across flats.

Boltheads. *Form.*—The head form is square or hexagonal in the unfinished, regular and heavy series. All other heads are hexagonal only.

Bearing Surfaces.—The bearing surfaces of the heads are either plain or washer faced.

Tops of Heads.—The tops of the heads are flat and chamfered. The angle of chamfer with the top surface is 25° (drawn 30°) for square and 30° for hexagonal heads. The diameter of the top circle is the width across flats, with a tolerance of minus 15 per cent.

Height of Head.—The height of head is the distance from the top to the bearing surface, and thus for washer-type heads includes the thickness of the washer.

Nuts. *Form.*—The nut is square or hexagonal in the unfinished, regular and heavy series. All others are hexagonal only.

Bearing Surfaces.—The bearing surfaces of nuts are plain, washer faced or chamfered.

Tops of Nuts.—The tops of nuts are flat, or chamfered, or (except in jam nuts) washer crowned. For flat and chamfer nuts the angle of chamfer with the top surface is 25° (drawn 30°) for square and 30° for hexagonal nuts; the diameter of the top circle is the width across flats with a tolerance of minus 15 per cent.

Thickness of Nuts.—The thickness of a nut is the over-all distance from the top to the bearing surface, and thus includes the washer face.

219. American Standard Bolts and Nuts.—The former "United States Standard" for the sizes of boltheads and nuts is now replaced by the "American Standard Wrench-head Bolts and Nuts and Wrench Openings," first approved in 1927, revised in 1933 and again in 1941.

The Standard includes three series as follows:

Regular Series Boltheads and Nuts.—Regular boltheads and nuts are for general use. The dimensions and the resulting strengths of these boltheads and nuts are based on the theoretical analysis of the stresses and on results of numerous tests.

Heavy Series Boltheads and Nuts.—Heavy boltheads and nuts are for use where greater bearing surface is necessary, that is, where a large clearance between the bolt and hole or a greater wrench-bearing surface is considered essential.

Light Series Nuts.—Light nuts have smaller dimensions across flats than regular series nuts. They are used where an extreme saving in weight and material is desired.

220. Standard Forms of Special-purpose Nuts. *Jam Nuts.*—American Standard jam nuts provide the commonest form of locking device, Fig. 521. They have the same dimensions as corresponding full nuts, except thickness, and are made in regular, heavy and light series, semifinished and (except light series) unfinished. The tops in all series and finishes are flat and chamfered. Bearing surfaces are plain on the unfinished, and washer faced or chamfered on the semifinished. The form is hexagonal only. For detail dimensions, see Appendix.

Slotted nuts, Fig. 521, are used principally in automotive work. They are made in regular, heavy, light and light-thick series, semifinished only. Tops in all series are flat and chamfered. Bearing surfaces are washer faced or chamfered. Slots have square or round bottom, at the option of the manufacturer. For detail dimensions see Appendix.

Light-thick nuts have the same dimensions, except thickness, as the corresponding sizes in the light series. See Appendix. They are made only in hexagonal form, semifinished. Tops are flat and chamfered. Bearing surfaces are washer faced or chamfered.

Light castle nuts are similar in use to slotted nuts. Bearing surfaces are washer faced or chamfered. Bottoms of slots are square or round. See Appendix for detail dimensions.

Machine-screw nuts are hexagonal. The tops are flat and chamfered. Bearing surfaces are plain, washer faced or chamfered. Sizes are by number except three fractional sizes. See Appendix.

Stove-bolt nuts are square, and the tops and bottoms are flat without chamfer. The width across flats and the thickness is the same as hexagonal machine-screw nuts. Two forms of threads are in use: the American Standard with Coarse and Fine Series and the Tap and Die Manufacturers Standard in which the width of the crest and root has been increased. The two are not interchangeable. The American Standard provides for nuts in the numbered sizes but most manufacturers list stove bolts in fractional sizes from $\frac{1}{8}''$ to $\frac{1}{2}''$.

Formulas.—The formulas upon which the dimensions and tolerances for the American Standard boltheads and nuts are based are given in the Appendix. The proportions are in terms of the diameter, with adjustments necessary in some sizes to eliminate small fractional measurements. For drawing purposes obtain actual dimensions from the tables. The regular series is for all ordinary uses and is always understood unless otherwise specified.

221. Classes of Finish.—The ASA specifies three classes of boltheads and nuts in both the regular and heavy series. These are (1) unfinished, (2) semifinished and (3) finished.

Unfinished boltheads and nuts are, except for the threads, not machined on any surface.

Semifinished boltheads and nuts are machined or otherwise formed to provide a smooth bearing surface. For boltheads this will be either a washer-faced or a plain bearing surface, and for nuts a washer-faced or a circular bearing surface made by chamfering the edges.

Finished boltheads or nuts are the same as semifinished except that the surfaces other than the bearing surface are machined for accuracy and appearance. The finish desired on all nonbearing surfaces of finished boltheads and nuts should be specified by the purchaser.

222. United States Standard Bolts and Nuts.—Before the adoption of the American Standard the United States Standard was in general use, and in some places it has not yet been superseded by the regular series of the

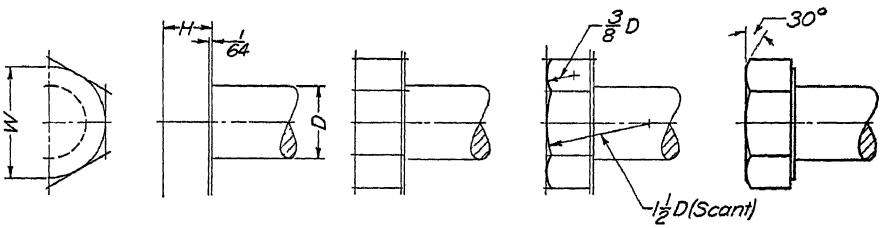


FIG. 513.—Stages in drawing a hex. head.

American Standard. The proportions of the United States Standard are $W = 1\frac{1}{2}D + \frac{1}{8}''$; height of head, $W/2$; thickness of nut, D. Thus, it will be noted the United States Standard is virtually the same as the heavy series of the American Standard, except that the angle of chamfer on the hexagon is 45° instead of 30° as in the American Standard. The "Unfinished Heavy" table may therefore be used as a table for the old United States Standard.

223. To draw an American standard bolt and nut the following information must be known: (1) the diameter, (2) the series, (3) the class of finish, (4) the length and (5) the kind of thread. Boltheads and nuts are always shown across corners on all views showing the faces unless there is some special reason for drawing them across flats. Figure 513 shows the stages in drawing a hexagon head. (1) Establish the diameter, the height of head and washer-face thickness. (2) Draw one-half of the end view and project edges of faces to (3). (4) Draw chamfer curves as circle-arc approximations to the actual curves, which are hyperbolas, in order. (*a*) Draw $1\frac{1}{2}D$ (scant) arc, obtaining radius directly from view (2) where $W = 1\frac{1}{2}D$ approximately. (*b*) Draw $\frac{3}{8}D$ arcs, obtaining radius by approximating

$\frac{3}{8}D$ from drawing. Centers are found by trial. (5) Draw 30° chamfers, flat surface on top of head and washer-face diameter.

Since the head and nut in like series and finishes differ only in thickness, time can be saved by carrying similar steps along together. Figure 514 is a progressive drawing of a square head across corners.

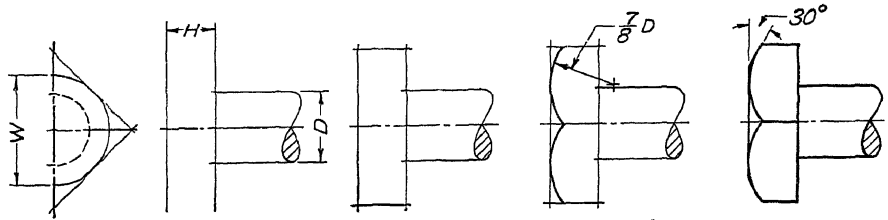


FIG. 514.—Stages in drawing a square head.

224. Dimensioning and Specifying an American Standard Bolt.—It is recommended that bolts be completely specified by note with the various items in the following definite order: (1) Diameter and length. (2) Material, if other than steel. (3) Class of finish. (4) Series (omitted if bolt is regular). (5) Type of head. (6) Type of nut if different from head. (7) Thread specifications

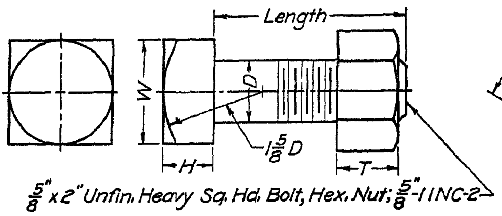


FIG. 515.—Am. Std. unfinished heavy bolt.

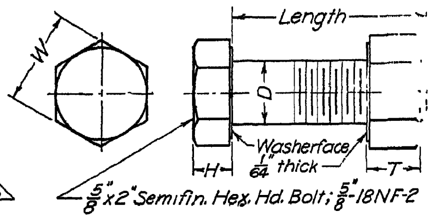


FIG. 516.—Am. Std. semifinished regular bolt.

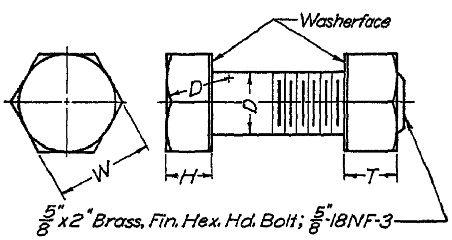


FIG. 517.—Am. Std. finished regular bolt.

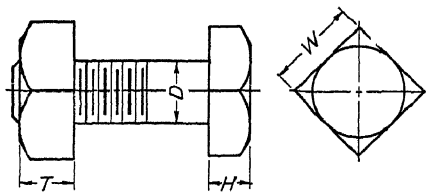


FIG. 518.—Am. Std. unfinished regular bolt.

Example: $\frac{1}{2} \times 4''$ copper unfinished heavy square-head bolt; steel, semifinished heavy hexagonal nut; $\frac{1}{2}''$-13 NC-2.

This is abbreviated as follows:

$\frac{1}{2}'' \times 4''$ Copper Unfin. Heavy Sq.-hd. Bolt.

Steel Semifin. Heavy Hex. Nut; $\frac{1}{2}''$-13 NC-2.

If bolt is steel and regular, and head and nut are like, the specification reads:

$\frac{1}{2}''$ × 4″ Semifin. Hex. Hd. Bolt and Nut; $\frac{1}{2}''$-13 NC-2.

Figures 515 to 519 inclusive show drawings, with proportions in terms of the diameter, and the form of notes to be used for specifying various bolts and nuts.

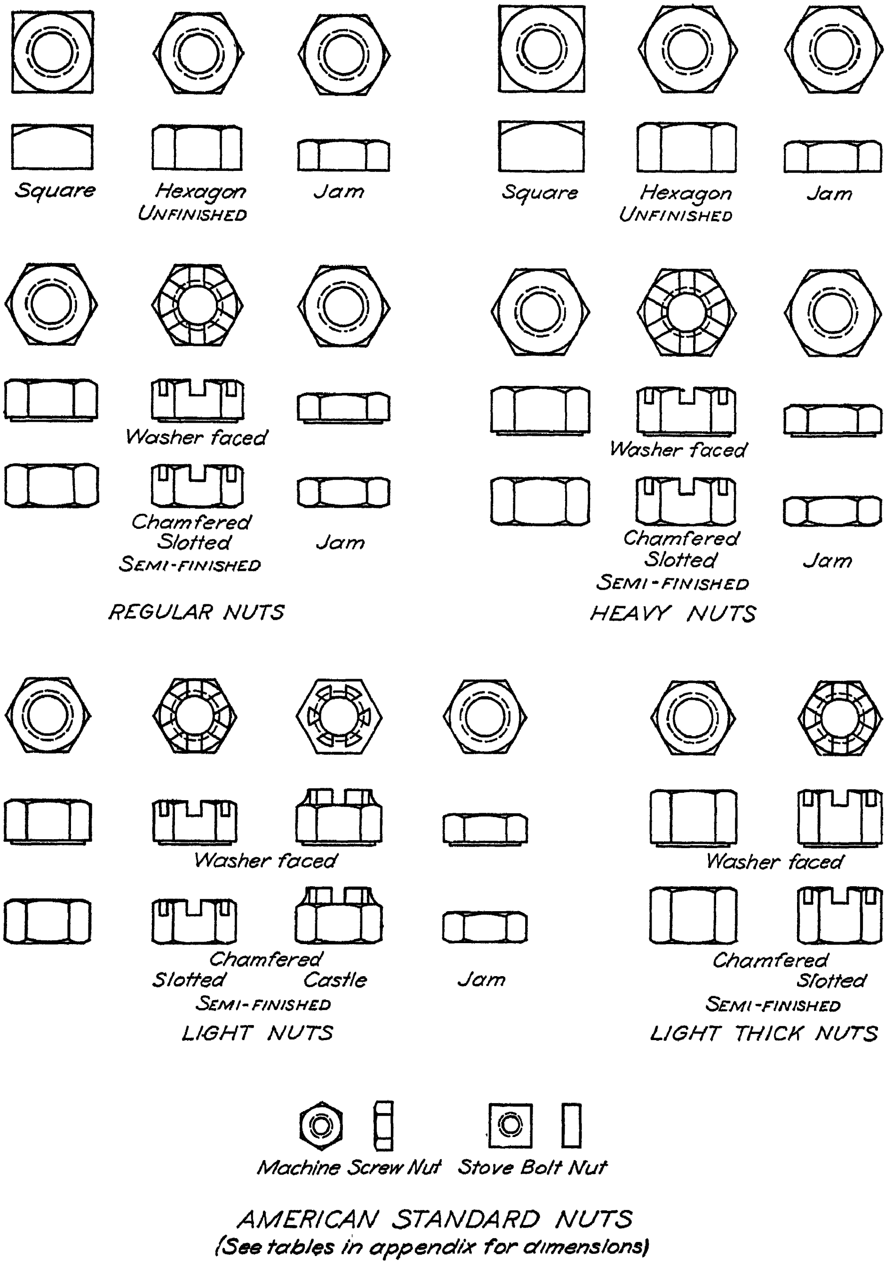


FIG. 519.—Various Am. Std. wrench-head nuts.

225. Studs.—Fig. 520. The stud, a rod threaded on both ends, is used when through bolts are not suitable, for parts which must be removed frequently, such as cylinder heads, chest covers, etc. One end is screwed tightly into a tapped hole, and the projecting stud guides the removable piece to position. The end to be screwed permanently into position is called the "stud end" and the opposite end the "nut end." The stud end is sometimes identified by leaving a projection on it. Studs have not yet been standardized by the ASA. The length of thread on the stud end is governed by the material tapped. See Fig. 511. The threads should jam at the top of the hole to prevent the stud from turning out when the nut is removed.

The length of thread on the nut end should be such that there is no danger of the nut binding before the parts are drawn together. The name "stud bolt" is often applied to a stud used as a through fastening with a nut on each end. The stud is specified by note as shown in Fig. 520*A*, with the various items in the following order: (1) Diameter and length. (2) Material if other than steel. (3) Thread specification and length of thread on nut end. (4) Type of nut. (5) Thread specification and length of thread on stud end.

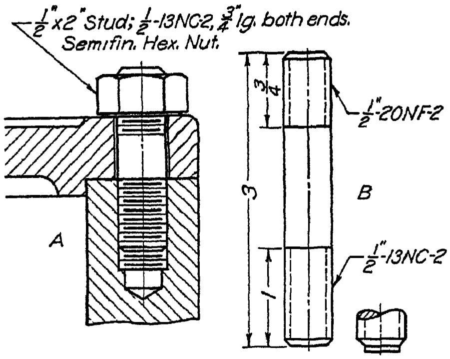


Fig. 520.—Studs.

Example: ½″ × 4″ Brass Stud; ½″-20 NF-2, 1″ Lg. with semifin. Hex. Nut and ½″-13 NC-2, ¾″ Lg. If threads on both ends are alike and material is steel, the note reads: ½″ × 4″ stud; ½″-13 NC-2, ¾″ Lg. both ends; with Semifin. Hex. Nut.

The stud may also be specified on a detail drawing as shown in Fig. 520 *B*.

226. Lock Nuts and Locking Devices.—Fig. 521. Many different locking devices are used to prevent nuts from working loose. A screw thread holds securely unless the parts are subject to impact and vibration, as in a railroad track joint or an automobile engine. A common device is the *jam nut, A*. American Standard jam nuts have the same dimensions as corresponding full nuts except the thickness. *Slotted nuts* to be held with cotter or wire, used largely in automotive work, are shown at *L*, and *castellated nuts* as used with fine and extra-fine threads on light tubular sections in aeronautical work, at *M*. At *B* is shown a *round nut* locked by means of a setscrew. A brass plug is placed under the setscrew to prevent damage to the thread. This is a common type of adjusting nut used in machine-tool practice. *C* is a lock nut, in which the threads are deformed after cutting. Patented spring washers such as are shown at *D*, *E* and *F* are common devices. There are three standard SAE spring lock washers: SAE

Light, SAE Standard and SAE Heavy; these are shown at *G* and *H* and are specified by giving nominal diameter and weight.

Example: ½″ SAE Heavy Lock Washer.

If special give nominal diameter with width and thickness of steel section.

Example: ½ × 3/16 × 3/32 SAE Lock Washer (see Appendix).

J is typical of a number of lock washers which are bent after the nut is in place. *Spring cotters* are used as at *K*. *N* and *O* are self-explanatory. At *U* is shown a nut slotted and then permanently deformed. When this

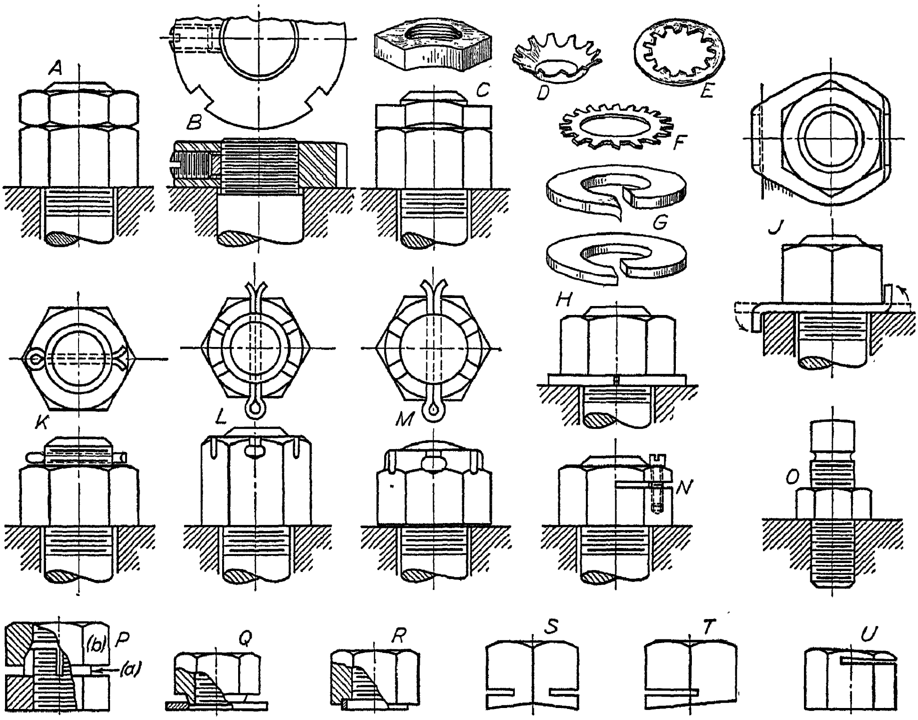


Fig. 521.—Locking devices.

nut is screwed on a bolt the slot is forced open, increasing the frictional resistance to rotation. Similar results are obtained by deforming the nut as it tightens, as at *S* and *T*. Another device *R* uses a soft copper ring in a grooved recess in the nut. Tightening the nut causes the copper to flow into the thread recesses. Other types of thread deformations are used, such as is shown at *Q*, where a conical projection on the nut is drawn into a steel washer. Device *P* consists of two nuts. The top of nut *a* is a cylinder having four radial slots. The jam nut *b* has a conical recess in its bearing face. Nut *a* is first screwed down tight on the work. Nut *b* is then screwed on the bolt and tightened. These illustrate only a few of the many locking devices available.

227. Dardelet Screw Thread.—The Dardelet self-locking thread is a special thread requiring no auxiliary locking devices to hold the nut under vibration. Its profile is quite similar to the Acme thread but the roots of

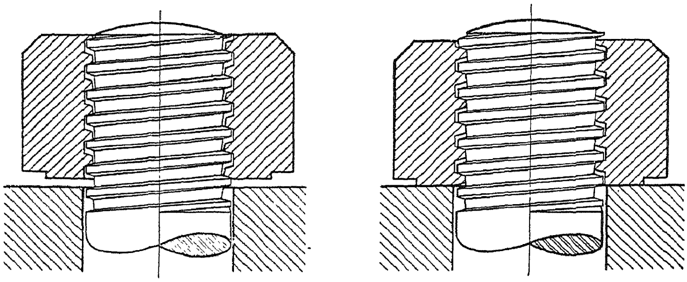


Fig. 522.—Dardelet thread, unlocked and locked.

the external thread and the crests of the internal thread are tapered about 6° to the axis. The nut screws on very easily until the bearing surface comes to rest, then the wrench torque forces the two tapered surfaces into binding contact. Figure 522 shows the nut in unlocked and locked positions. In drawing Dardelet bolts and nuts the heads have the same proportions as the American Standard Regular Series. The nuts are the same except in thickness. For drawing purposes the thickness may be made $1\frac{1}{8}D$.

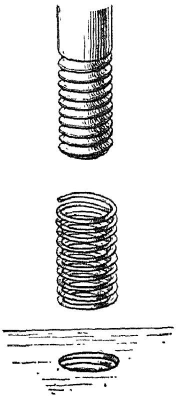


Fig. 523.—Aero thread.

Aero Thread.—Fig. 523. In the aero-thread system a coil-spring insert is used in the tapped hole. This makes it possible to use high-strength cap screws and studs in comparatively soft material such as aluminum and magnesium alloys. The insert is assembled in the tapped hole and provides a smooth hard bearing surface for the screw. The thread in the tapped hole has the same form as the American Standard screw thread. The screw has a shallow circular form. Special dies for cutting the thread and a special tool for assembling the insert are necessary.

228. Cap screws, Fig. 524, differ from bolts in that they are used for fastening two pieces together by passing through a clear hole in one and screwing into a tapped hole in the other. Cap screws are used on machine tools and other products requiring close dimensions and finished appearances. Threads are class 3 fit, Coarse or Fine Series. Full-finished cap screws are accurately made to proportions set up by the ASA. The semi-finished screws do not always conform to the exact basic formulas.

The five types of heads shown in Fig. 524 are standard. Detail proportions and dimensions are given in the Appendix.

The steps in drawing a hex. head are the same as for hex. head bolts. For other types of heads see Fig. 524 and obtain sizes from tables in the Appendix. On the drawing it is not necessary to show clearance between

the fastening and machine parts. However, clearance must be provided in the dimensioning.

Cap screws are specified by note, with the several items in the following order: (1) Diameter and length. (2) Material if other than steel. (3) Type of head. (4) Thread specifications.

Example: $\frac{3}{8}'' \times 1\frac{1}{2}''$ Brass Hex. Hd. Cap screw $\frac{3}{8}''$-16 NC-3.

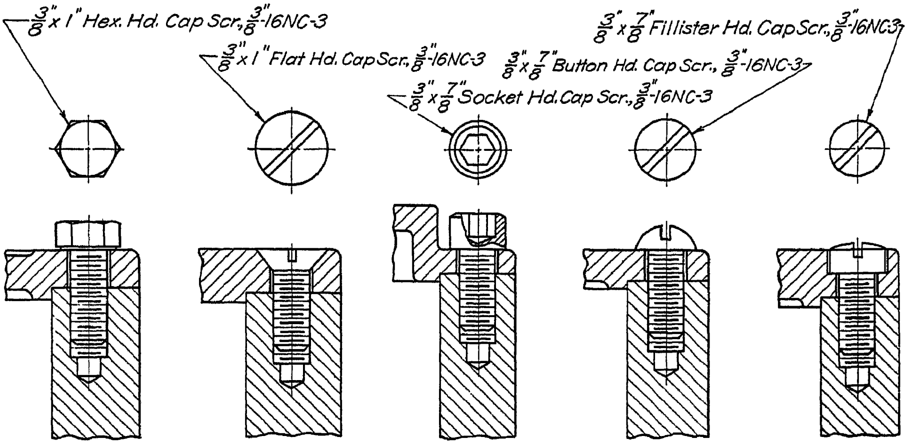


FIG. 524.—Am. Std. cap screws.

229. Machine screws are similar in appearance to cap screws. The heads have like names with the exception of the semielliptical shape, which is "round head" for machine screws and "buttonhead" for cap screws. The four standard shapes of heads are shown in Fig. 525. Numerous other shapes are available for special uses. All heads are slotted as a protection to the screw. Threads are either Coarse or Fine Series. Diameters are nominal except in three fractional sizes of $\frac{1}{4}''$, $\frac{5}{16}''$ and $\frac{3}{8}''$. Machine screws are specified by note giving in order: (1) Diameter. (2) Threads per inch. (3) Length. (4) Material if other than steel. (5) Type of head.

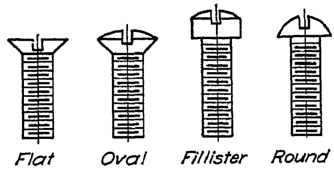


FIG. 525.—Am. Std. machine screws.

Example: No. 10-24 $\times$ $\frac{1}{2}''$ Brass Fillister Head Machine Screw.

The American Standard dimensions for the standard heads and sizes are given in the Appendix.

230. American standard unslotted round-head bolts are used only as through fastenings. In this group are included carriage bolts, step bolts, buttonhead bolts and countersunk bolts. Several of the forms are for wood construction, having square sections, ribs or fins under the head to prevent the fastening from turning. Threads are American Standard Coarse Series with the threads cut or rolled. A table in the Appendix shows the form of

heads and proportions suitable for drawing purposes. Exact dimensions may be obtained from ASA pamphlet 18.5-1939.

231. Setscrews made of hardened steel are used for holding two parts in relative position, being screwed through one part and having the point

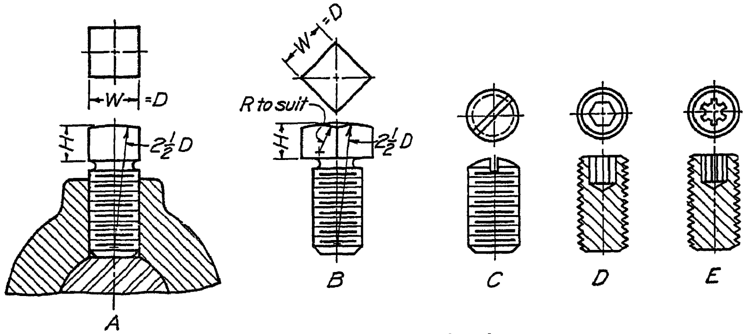


FIG. 526.—Set-screw heads.

set against the other. The American Standard square-headed and some forms of headless screws are shown in Fig. 526. Types of points are shown in Fig. 527. Dimensions for drawing purposes are given in the Appendix.

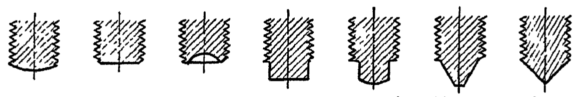


FIG. 527.—Set-screw points.

Headless setscrews are made to comply with the safety code of factory inspection laws, which are very strict regarding the use of projecting screws on moving parts. Setscrews are specified by giving in order: (1) Diameter. (2) Length. (3) Type of head. (4) Type of point. (5) Thread specification.

Example: ¼″ × ¾″ sq.-hd. cone-pointed setscrew, ¼″-20 NC-2.

232. Stripper Bolts or Shoulder Screws.—Fig. 528. This fastening was formerly used almost exclusively in die work for attaching strippers to punches. It is now widely used for holding machine parts together, such as cam attachments, links, levers and oscillating parts. Four diameters in lengths from 1 to 7 inches are standard with manufacturers. Threads are Coarse Series. Detail dimensions are in the Appendix.

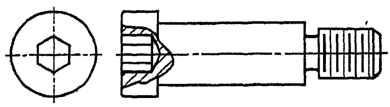


FIG. 528.—Stripper bolt or shoulder screw.

233. Plow Bolts.—Fig. 529. Four types of plow bolts from 182 varieties in use have been standardized by the ASA. For their particular uses, proportions, etc., see ASA bulletin B18f-1928.

234. Parker-Kalon Hardened Self-tapping Screws.—Fig. 530. Recent years have seen the development and wide use of a group of fastenings with a special hardened thread, which form their own internal threads in the

material when driven into a hole of the proper size. They do not offer the best means of making every fastening and cannot replace bolts, machine screws, rivets etc., under all conditions. However, under many conditions these screws give a combination of speed, security and ease of working that make them the preferred fastening. Many factors, such as size of fastening, size of holes, amount of engagement, kind of material, etc., affect satisfactory results. Data sheets from the manufacturers giving this detailed information are available to instructors of engineering drawing, machine design, etc., for classroom use. Parker-Kalon Self-tapping *Cap Screws* are for light and heavy assemblies; for fastenings to sheet metal, steel plate and structural shapes up to ½″ thick; to brass, aluminum and die castings; to slate, asbestos, etc. This screw is used by drilling a hole of the specified diameter and turning the fastening into it. No tapping is necessary, and the screw may be removed and replaced in the same hole without affecting

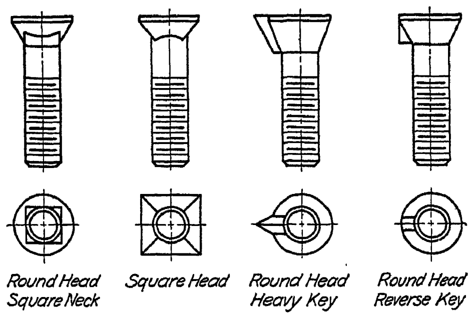


Fig. 529.—Am. Std. plow bolts.

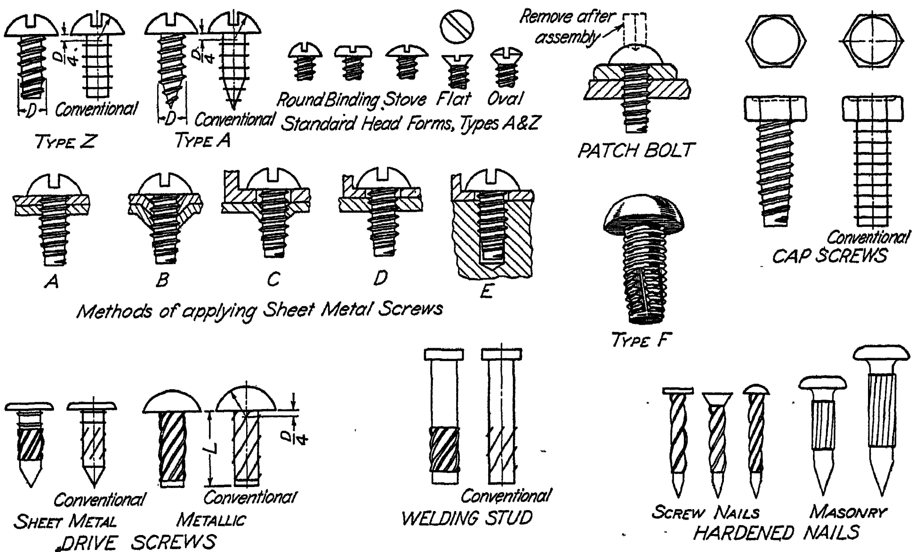


Fig. 530.—Parker-Kalon hardened self-tapping screws.

the holding power. Threads are special, and the drill size is important. See tables in Appendix.

Hardened self-tapping sheet-metal screws are made with two types of points known commercially as type *A* and type *Z*. The essential difference

is that type *A* has a gimlet point, while type *Z* has a blunt point. Standard head forms are shown in Fig. 530. Many special head forms are available. They may be driven with hand or power screwdrivers or with automatic feed machines. The different methods of applying Fig. 530 are:

At *A*.—Two sheets of light-gage sheet metal are drilled or clean punched the same size in both sheets.

At *B*.—Two sheets of light-gage sheet metal are punched together so that the burrs are nested. This gives a stronger fastening than at *A*.

At *C*.—A part with clearance holes is fastened to light-gage sheet metal. The sheet metal should be pierced, providing a greater thread engagement.

At *D*.—A part with clearance holes is fastened to heavy-gage sheet metal. The sheet metal should be drilled or clean punched.

At *E*.—A part is fastened to a solid section of aluminum, die casting, etc. Clearance holes should be provided in the part to be fastened, to permit the parts to be drawn tightly together.

Hardened self-tapping screws known commercially as *type F* are used in materials of a crumbling or granular nature, such as cast and malleable iron, plasters, bakelite, etc. The tap-fluted pilot cuts a thread in the material as it is turned in. The threads are American Standard Coarse and Fine Series and may be used with a nut or replaced with a standard machine screw if necessary. This screw is used by first drilling a hole of suitable diameter and turning in the fastening. Drill size, maximum and minimum penetration factors are important for satisfactory results, and should be obtained from manufacturers' catalogues.

Hardened metallic drivescrews are for making permanent fastenings to iron, brass, aluminum castings, steel, plastics, etc. They may be hammered in or driven with a press. The material into which they are driven should have a thickness not less than the body diameter of the screw.

Sheet-metal drivescrews are used by automotive manufacturers, body builders and trim shops for attaching upholstering, trim pads, windlace, etc., to metal bodies. Severe vibration does not cause these screws to back out.

To use, hammer the screws into drilled, clean punched, or pierced holes of the proper size. They may be driven with a hopper-feed press without drilling or punching holes in the metal.

Self-tapping patch bolts are used for making repairs to steel plate and structural shapes up to ½″ thick, in railroad, ship and bridge work. To use, make a hole of the proper size and turn in the bolt with a socket or end wrench. Cut off the square-headed shank (which is not hardened) and dress the head with a file. For satisfactory results the hole sizes are important and differ for materials of different thicknesses. Consult manufacturers' catalogues for recommended sizes.

Welding studs are used in making welds on heavy iron castings. They are used by drilling holes of proper size and driving in the studs. As the studs are driven into place, their hardened spiral thread forms a thread in

the casting that provides a combination of wedge and screw which results in a perfect bond between the casting and the weld.

Hardened masonry nails are used by sheet-metal workers, roofers, plumbers, electrical contractors, sign makers, etc., for making fastenings to masonry. To use, drill holes of the proper size and drive in the nails with a hammer. In comparatively soft masonry, such as mortar, cinder concrete, stucco, etc., the masonry nails ordinarily may be driven without drilling holes.

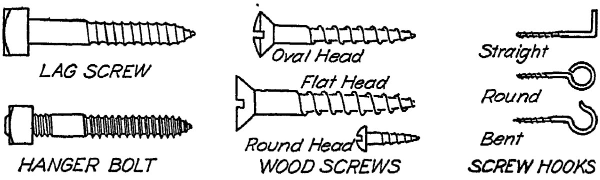


FIG. 531.—Wood screws.

Sheet-metal screw nails are used to fasten sheet metal to wood. They combine the easy application of a nail and the holding property of a screw. They are driven directly through the metal in light gages and through prepunched holes in heavier gages. They are available in a variety of sizes and head forms.

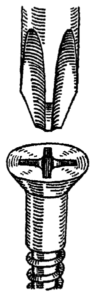


FIG. 532. —Phillips recessed head.

235. Wood screws have the threads proportioned to the relative holding strength of wood and metal. Three types of head—round, flat and oval—are standard, Fig. 531. Many kinds of finish are available, such as steel, blued, chromium, or nickel plated, etc. Wood screws are made with the regular screw-driver slot in the head or in a special form known as the "Phillips recessed head," Fig. 532. This form has many advantages over the regular type. It is self-centering and the driver can not slip out of the head. This permits the use of power drivers on operations that previously required careful hand driving. The Phillips head is also being adapted to all fastenings that formerly used the slotted head. Wood-screw diameters are designated by number.

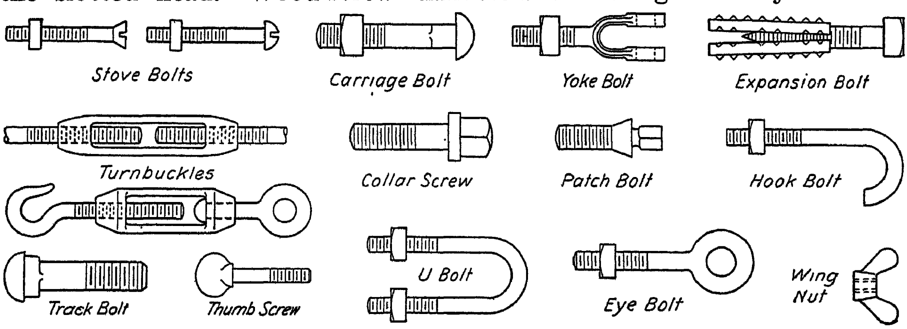


FIG. 533.—Various bolts and screws.

Other forms of wood fastenings are lag screws, hanger bolts and screw hooks, Fig. 531.

236. Other Forms of Fastenings.—Figure 533 illustrates the method of representing various other bolts and screws.

237. Dardelet self-locking rivet-bolts, Fig. 534, combine the principles of both a rivet and a bolt. Head dimensions are ABA (American Boiler Makers Association) standards. The nut conforms to the American Standard Heavy Series proportions with the exception of thickness, which is $\frac{3}{16}''$ to $\frac{1}{4}''$ greater, to provide for a counterbore $\frac{3}{32}''$ larger in diameter than the major thread diameter. Surrounding the body are a number of triangular shaped ribs extending axially from head to threaded end. Because no upsetting is involved, material high in shear and tensile strength is used for the bolt. Among the many advantages over field-driven rivets are elimination of noise, body-bound fit, and high shear and tensile values.

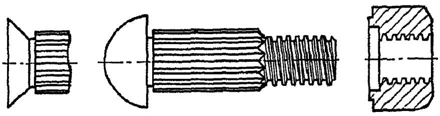


FIG. 534.—Dardelet rivet bolt.

Dardelet rivet-bolts are carried in stock by licensed manufacturers and distributors in principal cities, from whom complete dimensions and specifications may be obtained.

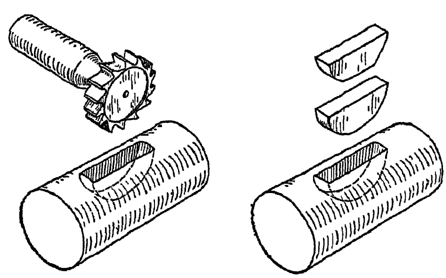


FIG. 535.—Woodruff keys.

238. Keys.—In machine drawing there is frequent occasion for representing keyed fastenings used in securing wheels, cranks, etc., to shafts. One of the commonest forms is the Woodruff key, a flat segmental disk with either round or flat bottom, as shown in Fig. 535. These are specified by number, and a table of standard sizes is given in the Appendix. A good basic rule for proportioning a Woodruff key to a given shaft is to have the width of the key one-fourth the diameter of the shaft and its radius equal to the radius of the shaft, selecting the standard key that comes nearest to these proportions. In drawing Woodruff keys, care should be taken to place the center for the arc above the top of the key to a distance equal to one-half the thickness of the saw used in splitting the blank. This amount is given in column E of the table in the Appendix.

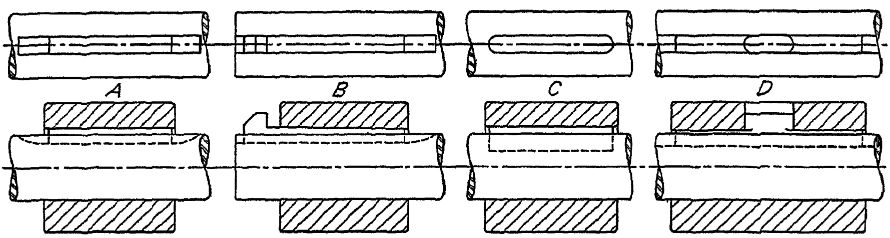


FIG. 536.—Square and flat keys.

Square and flat keys, both plain and tapered, have a variety of applications. Figure 536 shows at A a square key and at B a gib-head taper key.

Square- and flat-stock keys and taper-stock keys have been standardized by the ASA, and a table of sizes for use with various diameters of shafts is given in the Appendix. At C is a Pratt and Whitney key made with round ends. For sizes see table in Appendix. A *feather* is a straight key which allows a piece to slide lengthwise on a shaft while preventing rotation on the shaft. A sliding feather sometimes has a gib on each end and sometimes is made with one or more projections as at D. With these the keyway must, of course, extend to one end of the shaft.

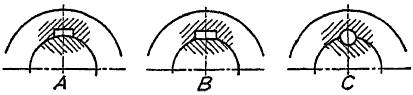


FIG. 537.—Keys for light duty.

Figure 537 shows three keys for light duty: the saddle key, the flat key and the pin or Nordberg key, which is used at the end of a shaft, as, for example, in fastening a handwheel. A taper pin is driven into a tapered hole made by drilling and reaming the shaft and hub together. The material of both pieces should be the same, for machining reasons.

Figure 538 shows some forms of heavy-duty keys. A is the Barth key, an improvement on the flat spline, B is the Kennedy key and C the Lewis key for driving in one direction, in both of which the line of shear is on the diagonal. D and E are two forms of splined shaft, widely used instead of keyed shafts.

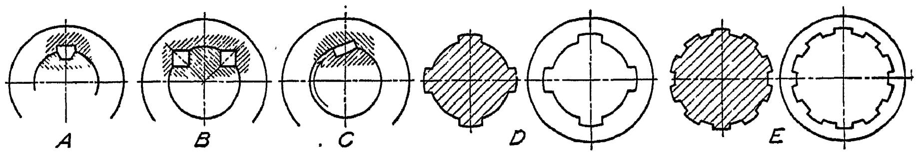


FIG. 538.—Keys for heavy duty.

239. Rivets.—Rivets are used for making permanent fastenings, generally between pieces of sheet or rolled metal. They are round bars of steel or wrought iron with a head formed on one end, and are put in place red hot so that a head may be formed on the other end by pressing or hammering. Rivet holes are punched, punched and reamed, or drilled, $\frac{1}{16}''$ larger than the diameter of the rivet, and the shank of the rivet is made just long enough to give sufficient metal to fill the hole completely and make the head.

It is not within our scope to consider the design of riveted joints, but we are concerned with the methods of representation. The two general uses of rivets are in structural-steel construction and in boiler and tank work. In the former only two kinds of heads are needed: buttonheads and countersunk heads. The standard symbols used in structural work are given on page 490.

For boiler and tank work, pressure against the head as well as shear must be considered, and the heads shown in Fig. 539 are used.

Plates are connected by either lap joints or butt joints. Single- and double-riveted lap joints and single and double straps are illustrated in Fig. 540.

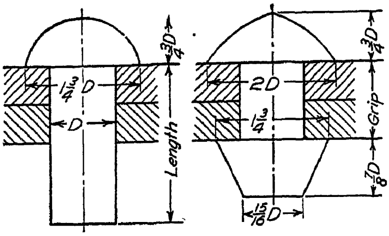


FIG. 539.—Boiler and tank rivets.

The American Standard proportions for the heads of small rivets are shown in Fig. 541. Standard countersunk aircraft rivets have an angle of 100°.

Explosive-type Rivets.—A novel method of blind riveting has been introduced recently, primarily for airplane construction and repair under conditions where "bucking up" is difficult or impossible.

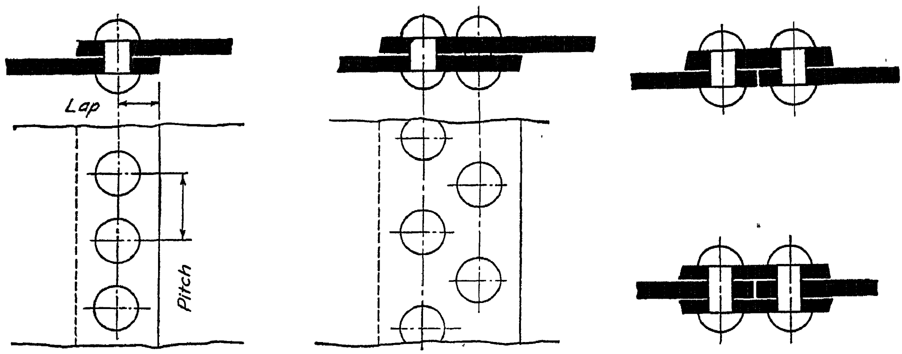


FIG. 540.—Lap joints and butt joints.

The du Pont rivet, Fig. 542, contains a small cavity filled with a charge which is fired by the application of an electrically heated tool to the machine-formed head. There is some compression of the shank and some

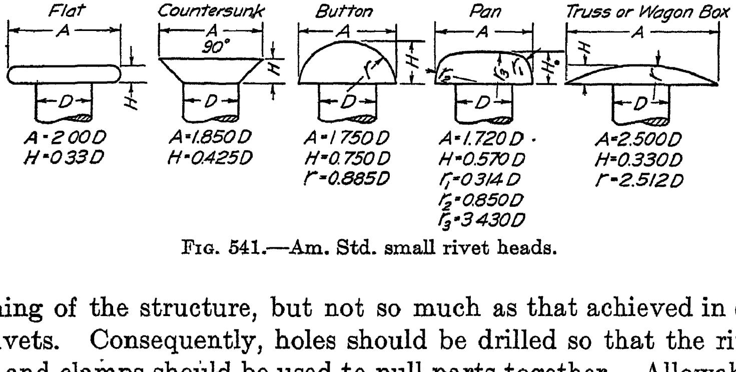


FIG. 541.—Am. Std. small rivet heads.

tightening of the structure, but not so much as that achieved in driving solid rivets. Consequently, holes should be drilled so that the rivets fit snugly and clamps should be used to pull parts together. Allowable grip lengths are specified by the manufacturer. In aluminum alloys, properly

expanded rivets have 85 to 90 per cent of the strength of the corresponding rivets of the conventional type.

240. Helical Springs.—Figure 543 shows the method of drawing the true projection of a helical spring with round section, by constructing the helix of the center line of the section, drawing on it a number of circles of the diameter of the wire and drawing an envelope curve tangent to the circles.

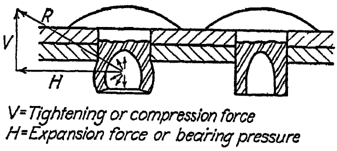


FIG. 542.—Explosive-type rivet.

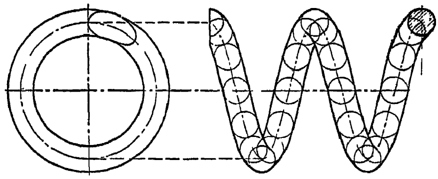


FIG. 543.—Spring, true projection.

This surface is known geometrically as a "serpentine." On working drawings, springs are drawn with straight lines, and when in small size with single-line representation. Compression springs are drawn to their free length. Figure 544 shows several conventional springs. The top view of the conical spring may be drawn as a four-center or two-center involute.

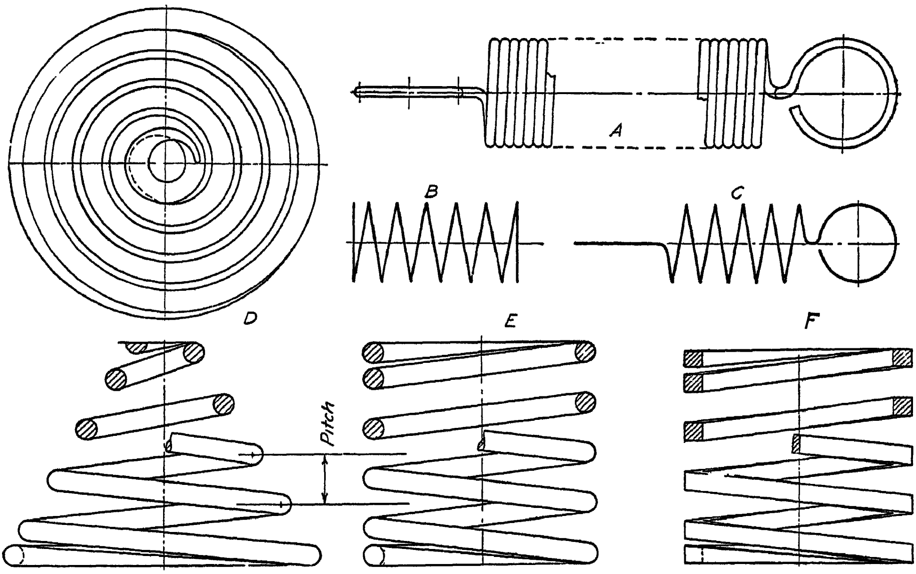


FIG. 544.—Springs, conventional.

A is a tension spring, illustrating the use of "ditto lines." *B* and *C* are single-line conventions. Helical springs should have their line of action coincide with the axis; hence compression springs have ends "closed and ground" as shown on *D*, *E* and *F*. By this is meant that the last coil has its lead gradually reduced to zero, touching the previous coil at the end of the last turn. Then the end is ground flat, giving approximately 50 to 80 per

cent bearing area, upon which the spring can stand unsupported with its axis vertical.

Helical springs are specified by giving the wire gage, the number of coils, the inside diameter of the coils and the free length.

PROBLEMS

Group I. Helices.

1. Draw three complete turns of a helix, diameter 3″, pitch 1¼″.

2. Draw three complete turns of a conical helix, top and front views, with 1½″ pitch, whose large diameter is 4″ and small diameter 1½″.

3. Draw four complete turns, two in section and two in full view of a helical spring made of ⅜″ square stock. Outside diameter 3½″, pitch 1½″.

4. Draw a helical spring 4″ long made of ½″ round stock. Outside diameter 3″, pitch 1″.

Group II. Screw Threads.

5. Draw two views of a square-thread screw and a section of the nut, separated; diameter 2½″, pitch ¾″, length of screw 3″. Nut American Standard semifinished hex. (except threads).

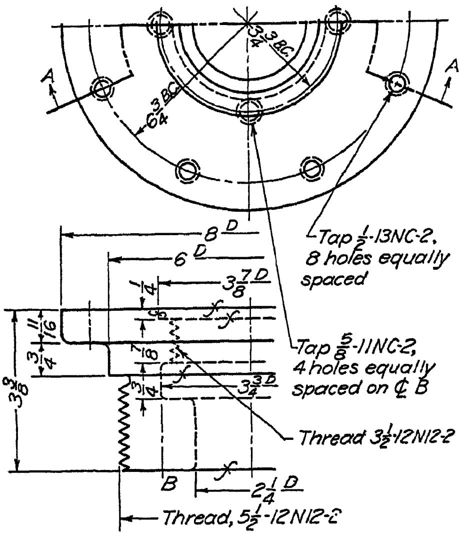


FIG. 545.—Valve ring.

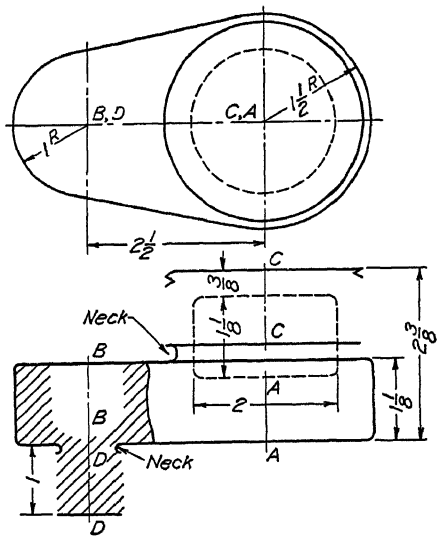


FIG. 546.—Rocker.

6. Same as Prob. 5 but for V-thread with ½″ pitch.

7. Draw in section the following forms of screw threads, 1″ pitch: American Standard; Acme; Whitworth; square.

8. Draw screws 2″ diameter and 3½″ long: single square thread, pitch ½″; single V-thread, pitch ¼″; double V-thread, pitch ½″; left-hand double square thread, pitch ½″.

9. Draw the complete views of the valve ring, Fig. 545, showing one view as a section *A-A*. Material, cast steel. Space 10″ × 15″.

10. Complete the views of the cast-steel rocker, Fig. 546, showing screw threads and tapped holes as follows: On center line *A-A*, tap, 2″8 N8-2; on center line *B-B*, for cap screw, ½″13 NC-2; on center line *C-C*, 2¾″12 N12-2; on center line *D-D*, ⅞″14 NF-3. Space 7″ × 10″.

Group III. Bolts.

11. Draw one view of an American Standard, regular, semifinished, hex-head bolt and nut across corners. Diameter 1″ length 5″. See table in Appendix for length of thread.

12. Same as Prob. 11 for an unfinished bolt and nut.

13. Same as Prob. 11 for a square-headed unfinished bolt and nut, Heavy Series.

14. Draw four ½″ × 1½″ cap screws, each with a different kind of head. Name and specify each.

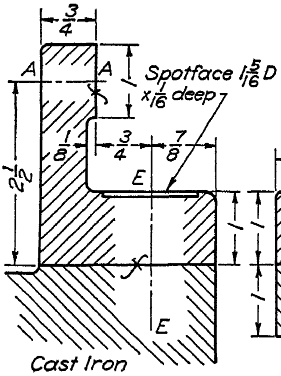


FIG. 547.

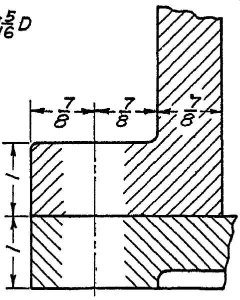


FIG. 548.

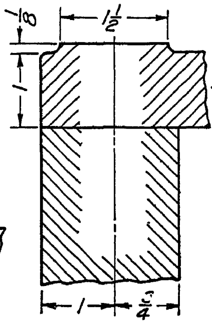


FIG. 549.

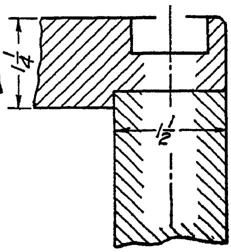


FIG. 550.

15. Fig. 547. Fasten the pieces together on center line *E-E* with a ¾″ American Standard hex-head cap screw and lock washer. On center line *A-A* show a ⅝″ × 1¼″ stripper bolt.

16. Fig. 548. Fasten pieces together with a ¾″ heavy, semifinished hex-head bolt and nut.

17. Fig. 549. Fasten pieces together with a ¾″ stud and regular semifinished hex nut.

18. Fig. 550. Fasten pieces together with a ¾″ fillister-head cap screw.

19. Fig. 547. Fasten pieces together with a ¾″ stud and regular semifinished hex nut and ¾″ regular semifinished jam nut. On center line *A-A* show a ¾″ × 1″ stripper bolt.

20. Fig. 548. Fasten pieces together with a 1″ American Standard hex-head cap screw.

21. Fig. 549. Fasten pieces together with a ¾″ socket-head cap screw.

22. Fig. 550. Fasten pieces together with a ⅞″ socket-head cap screw.

23. Draw one view of an American Standard square-neck carriage bolt. Diameter 1″, length 5″, with American Standard regular unfinished square nut. See Appendix for proportions.

24. Draw one view of an American Standard rib-neck carriage bolt. Diameter ¾″, length 4″, with American Standard regular unfinished square nut. See Appendix for proportions.

25. Draw two views of a stripper bolt. Diameter ¾″; shoulder length 5″. See Appendix for proportions of stripper bolts, or shoulder screws.

26. Draw two views of an American Standard socket-head cap screw, diameter 1¼″; length 6″.

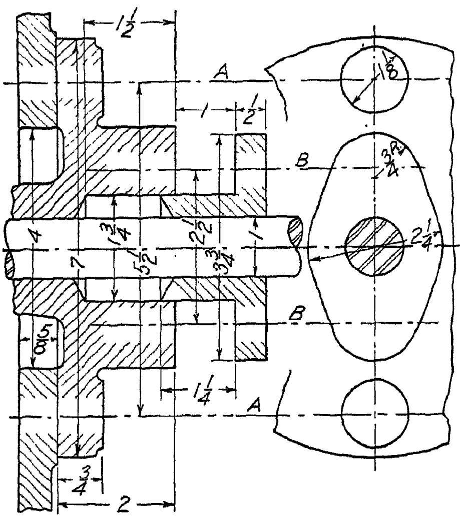


Fig. 551.—Stuffing box and gland.

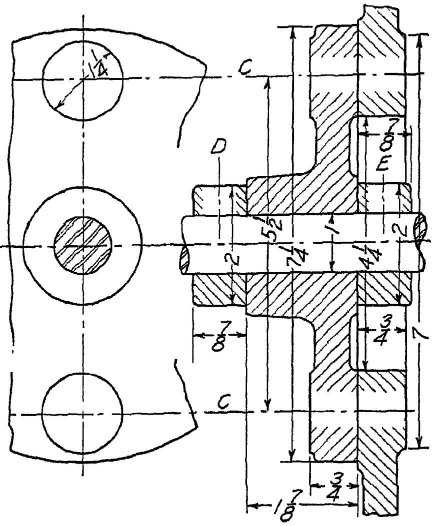


Fig. 552.—Bearing plate.

27. Fig. 551. Draw the stuffing box and gland, showing the required fastenings. Dimension fastenings only. On C.L's *A* show ½″ hex-head cap screws (six required). On C.L's *B* show ½″ studs and standard hex nuts. Supply missing dimensions.

28. Fig. 552. Draw the bearing plate, showing the required fastenings. On C.L's *C* show ½″ hex bolts and nuts (four required). On C.L. *D* show ½″ safety setscrew. On C.L. *E* show ½″ American Standard square-headed setscrew. Setscrews to have cone points. Supply missing dimensions.

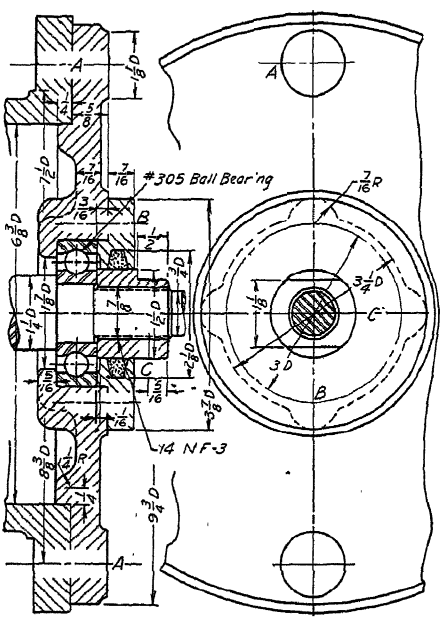


Fig. 553.—Ball-bearing head.

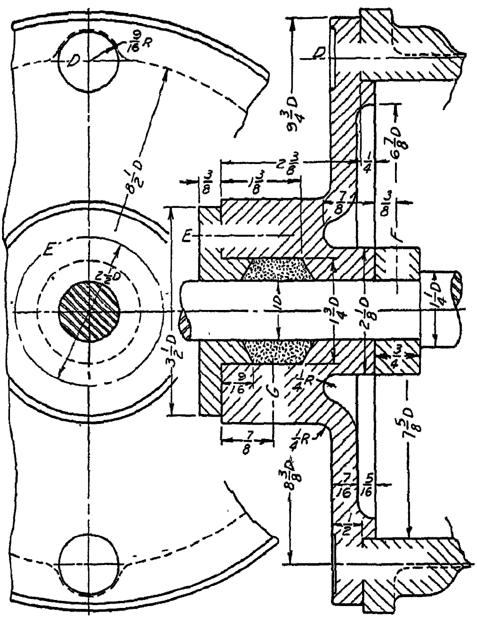


Fig. 554.—Plain bearing head.

Problems 27 and 28 may be drawn together on an 11″ × 17″ sheet, or on separate sheets, showing full diameter of flanges.

29. Fig. 553. Draw the ball-bearing head, showing the required fastenings. On C.L's *A* show ½″ × 1¾″ finished hex-head bolts and nuts (six required), with heads to left and shown across flats. Note that this design prevents the heads from turning. On C.L's *B* show 5⁄16″ × ¾″ fillister-headed cap screws (four required). On C.L. *C* show a ⅜″ × ½″ cone-pointed, safety setscrew. Spot shaft with nut in position. Supply missing dimensions.

30. Fig. 554. Draw the plain bearing head, showing the required fastenings. On C.L's *D* show ½″ × 2″ studs and nuts (six required). Spot face 1″ *D* × 1⁄16″ deep. On C.L.'s *E* show ⅜″ × 1″ hex.-head cap screws (four required). On C.L. *F* show a 7⁄16″ × ⅞″ American Standard cone-pointed setscrew. On C.L. *G* show a 29⁄64″ drilled hole plugged with a ¼″ pipe plug. This is for gun-packing the gland. Supply missing dimensions.

Problems 29 and 30 may be drawn together on an 11″ × 17″ sheet, or on separate sheets, showing full diameter of flanges.

Group IV. Keys and Rivets (Key sizes will be found in Appendix).

31. Fig. 555. Draw hub and shaft as shown, with a Woodruff key in position.

32. Fig. 556. Draw hub and shaft as shown, with a square key 2″ long in position.

33. Fig. 557. Draw hub and shaft as shown, with a gib-head key in position.

34. Fig. 558. Draw hub and shaft as shown, with a Pratt and Whitney key in position.

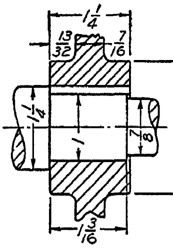


FIG. 555.

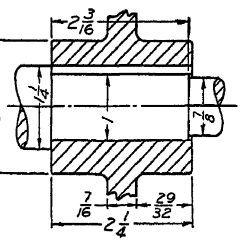


FIG. 556.

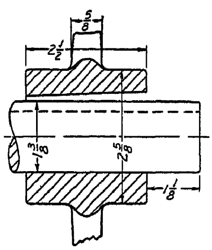


FIG. 557.

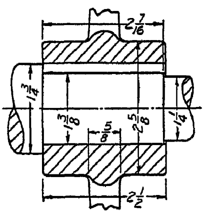


FIG. 558.

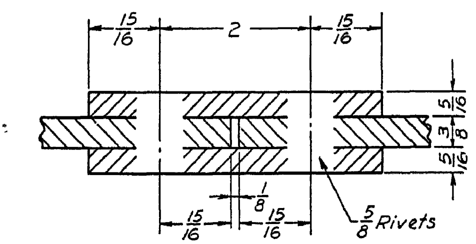


FIG. 559.

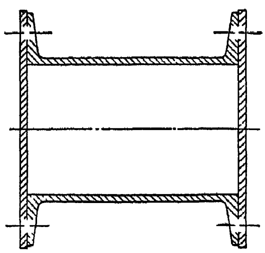


FIG. 560.

35. Fig. 559. Draw top view and section of single-riveted butt joint 10⅝″ long. Pitch of rivets 1¾″.

36. Fig. 560. Draw a column section made of 15″ × 33.9-lb. channels with cover plates as shown, using ⅞″ rivets (dimensions from the handbook of the American Institute of Steel Construction).

CHAPTER XIII

PIPING DRAWINGS

241. A familiarity with pipe and pipe fittings is necessary not only for making piping drawings but because pipe is often used as a material of construction. Standard pipe of steel or wrought iron up to 12″ in diameter is designated by its nominal inside diameter, which differs somewhat from the actual inside diameter. Early pipe manufacturers made the walls in the smaller sizes much too thick and in correcting this error in design took the excess from the inside to avoid changing the sizes of fittings. Three weights of pipe—standard, extra strong and double extra strong—are in common use. In the same nominal size all three have the same outside diameter, that of standard weight pipe, the added thickness for the extra and double extra strong being on the inside. Thus the outside diameter of 1″ pipe in all three weights is 1.315″, the inside diameter of standard 1″ pipe is 1.05″, of 1″ extra strong 0.951″, and of XX, 0.587″.

Many other weights of pipe are in more or less general use and are known by trade names, such as hydraulic pipe, merchant casing, API (American Petroleum Institute) pipe, etc. The American Standards Association in Bulletin ASA, B36.10-1939 gives a means of specifying wall thicknesses by a series of schedule numbers which indicate approximate values for the expression 1,000 $\times$ (P/S), where P is pressure and S the allowable stress. Recommended values for S may be obtained from the ASME Boiler Code, the American Standard Code for Pressure Piping (ASA, B31.1), etc. The designer computes the exact value of wall thickness as required for a given condition and selects from the schedule numbers the one nearest to the computed values. In the ASA system pipe is designated by giving nominal pipe size and wall thickness, or nominal pipe size and weight per foot.

All pipe over 12″ in diameter is designated as O.D. (outside diameter) pipe and is specified by its outside diameter and thickness of metal. Boiler tubes in all sizes are known by their outside diameters.

Seamless flexible metal tubing is used for conveying steam, gases and liquids in all types of equipment such as locomotives, Diesel engines, hydraulic presses, etc., where vibration is present, where outlets are not in alignment, and where there are moving parts.

Lead pipe and lead-lined pipe are used in chemical work. Cast-iron pipe is used for water and gas in underground mains and for drains in buildings.

Copper tubing is available in nominal diameters of ⅛″ to 12″ and in four weights known in the trade as types K, L, M and O. Type K is extra-heavy

hard, type *L* is heavy hard, type *M* is standard hard, and type *O* is light hard. American Standards specifications designate different weights as *class K*, *L* and *M* instead of *type K*, *L* and *M*.

Brass and copper pipe have the same nominal diameters as iron pipe but have thinner wall sections. There are two standard weights, regular and extra strong. Commercial lengths are 12 ft., with longer lengths made to order.

242. Pipe Threads.—Pipe is usually threaded on the ends for the purpose of screwing into fittings and making connections. The ASA in its tentative revision of May, 1940, provides two types of pipe thread, tapered and straight. The normal type employs a taper internal and taper external thread. This thread (originated in 1882 as the Briggs Standard) is illustrated in Fig. 561. The threads are cut on a taper of $\frac{1}{16}''$ per inch, measured on the diameter, thus fixing the distance a pipe enters a fitting and

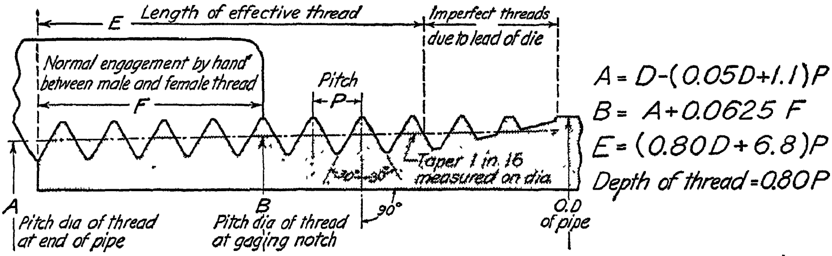


FIG. 561.—American Standard taper pipe thread.

ensuring a tight joint. Taper threads are recommended by the ASA for all uses with the exception of the following five types of joints: type 1, pressure-tight joints for pipe couplings; type 2, pressure-tight joints for grease-cup, fuel and oil fittings; type 3, free-fitting mechanical joints for fixtures; type 4, loose-fitting mechanical joints with lock nuts; type 5, loose-fitting mechanical joints for hose coupling. For these joints straight pipe threads may be used. The number of threads per inch is the same in taper and straight pipe threads. Actual diameters vary for the different types of joints. When needed they may be obtained from the ASA bulletins. A common practice is to use a taper external thread with a straight internal thread, on the assumption that the materials are sufficiently ductile to allow the threads to adjust themselves to the taper thread. All pipe threads are assumed to be tapered unless otherwise specified.

There is a great quantity of material now used which is generally classified as "oil country tubular goods." This material is so diversified that manufacturers' catalogues or API bulletins should be consulted for methods of specifying pipe, valves, fittings and casing threads. All API threads, with exception of drill-pipe threads, are identical in form with the American Standard pipe thread. The difference between the two systems is in the length of thread engagement, with the API having added length at the small

end. API drill-pipe threads have a rounded crest and root similar to the Whitworth thread.

Pipe threads are represented by the same conventional symbols as bolt threads. The taper is so slight that it does not show unless exaggerated.

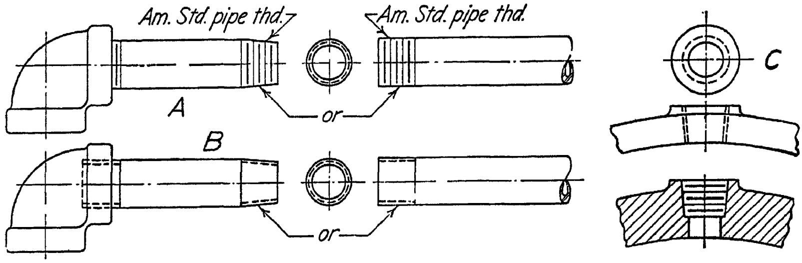


FIG. 562.—Conventional pipe thread.

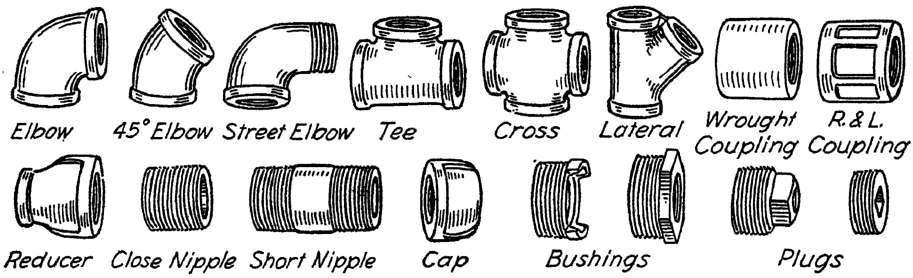


FIG. 563.—Screwed fittings.

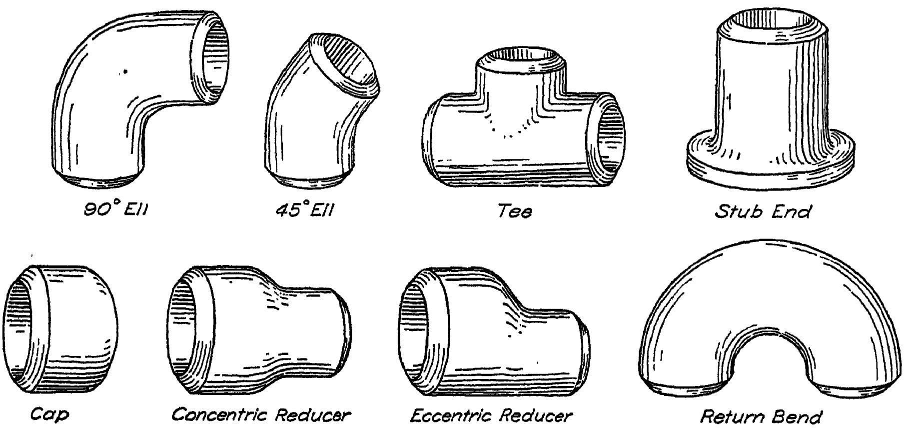


FIG. 564.—Butt-welding fittings.

It need not be indicated unless it is desired to call attention to it, as in Fig. 562. In plan view, as at C, the dotted circle should be the actual outside diameter of the pipe specified. The length of effective thread is $E = (0.80D + 6.8)P$, Fig. 561.

243. Pipe Fittings.—Pipe fittings are the parts used in connecting and "making up" pipe. They are usually cast iron or malleable iron, except

couplings, which are wrought or malleable iron. Brass and other alloys are employed for special uses. Pipe fittings are *screwed fittings*, Fig. 563; *butt-welding fittings*, Fig. 564; and *soldered-joint fittings*, Fig. 565. Tube couplings, Fig. 566, are usually patented arrangements, in general requiring the flaring of the ends of the tubing. Manufacturers' catalogues should be consulted for details and methods of specifying.

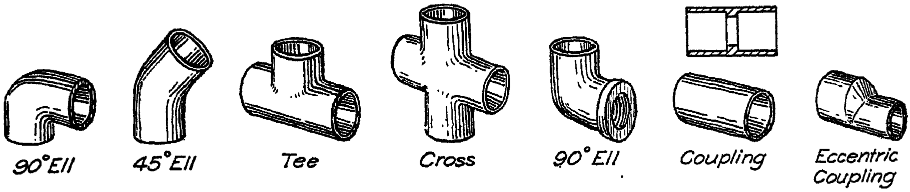


FIG. 565.—Soldered-joint fittings.

Straight sections of pipe are made in 12- to 20-ft. lengths and are connected by *couplings*. These are short cylinders, threaded on the inside. A right-hand coupling has right-hand threads at both ends. To close a system of piping, although a union is preferable, a *right-and-left coupling* is sometimes used. It is readily distinguished by the ribs on the outside, which are four in number on sizes up to 1 inch and six on sizes larger than one inch. Pipes are also connected by screwing them into cast-iron flanges and bolting the flanges together. Unless the pressures are very low, flanged fittings are recommended for all systems requiring pipe over 4 inches in diameter.

Nipples are short pieces of pipe threaded on both ends. If the threaded portions meet, the fitting is a *close nipple;* if there is a short unthreaded portion, it is a *short nipple*. Long and extra-long nipples range in length up to 12 inches.

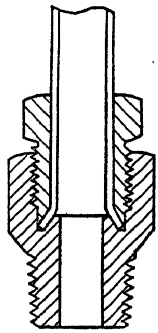


FIG. 566.—A tube fitting.

A *cap* is used to close the end of a pipe. A *plug* is used to close an opening in a fitting. A *bushing* is used to reduce the size of an opening.

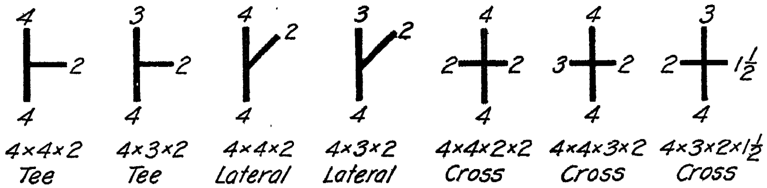


FIG. 567.—Order of specifying openings of reducing fittings.

Formerly each manufacturer had his own sizes of elbows, tees and other fittings, but now, to the great advantage of all pipe users, the ASA has standardized both screwed and flanged fittings.

244. Specifying Fittings.—Fittings are specified by the name, nominal pipe size and the material. When they connect more than one size of pipe the size of the largest run opening is given first, followed by the size at the opposite end of the run. The diagrams of Fig. 567 show the order of

specifying reducing fittings. The word "male" must follow the size of the opening if an external thread is wanted.

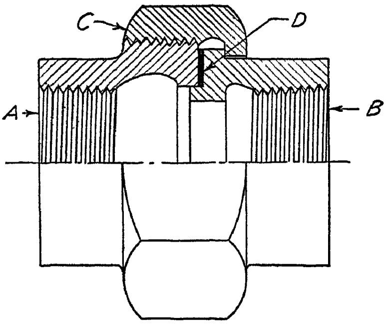


FIG. 568.—Screwed union.

245. Unions are used to close systems and to connect pipes that are to be taken down occasionally. A screwed union, Fig. 568, is composed of three pieces, two of which, *A* and *B*, are screwed firmly on the ends of the pipes to be connected. The third piece *C* draws them together, the gasket *D* forming a tight joint. Unions are also made with ground joints or with special metallic joints instead of gaskets. Other forms of screwed unions and union fittings are shown in Fig. 569. Flange unions in a variety of forms are used for large sizes of pipe.

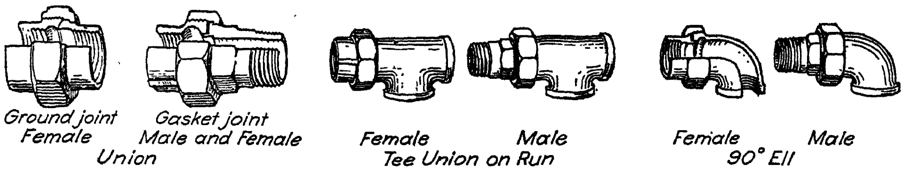


FIG. 569.—Screwed unions and union fittings.

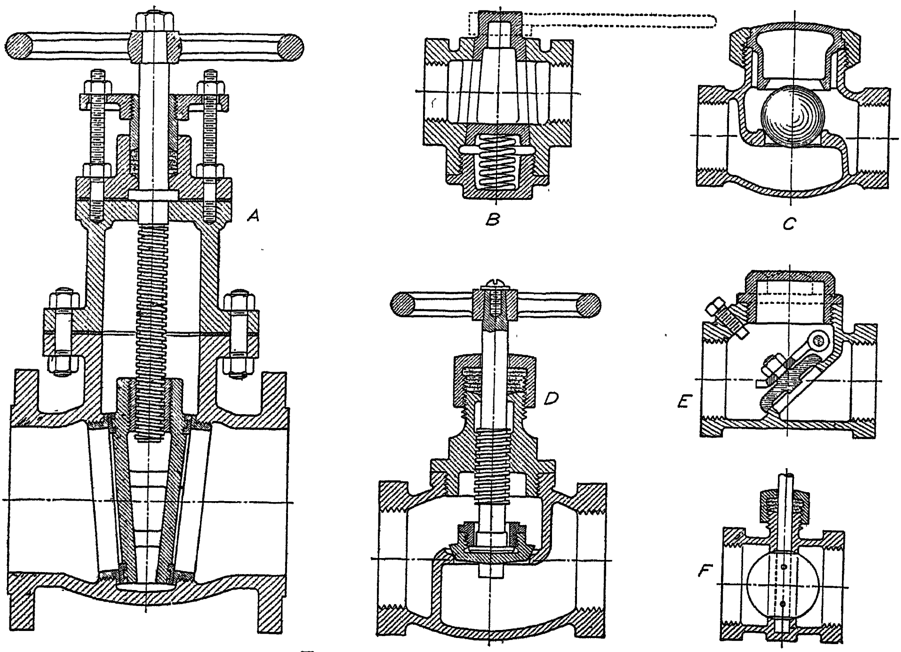


FIG. 570.—Sections of valves.

246. Valves.—Figure 570 shows a few types of valves used in piping. *A* is a gate valve, used for water and other liquids, as it allows a straight flow. *B* is a plug valve, opened and closed with a quarter turn; *C* a ball check

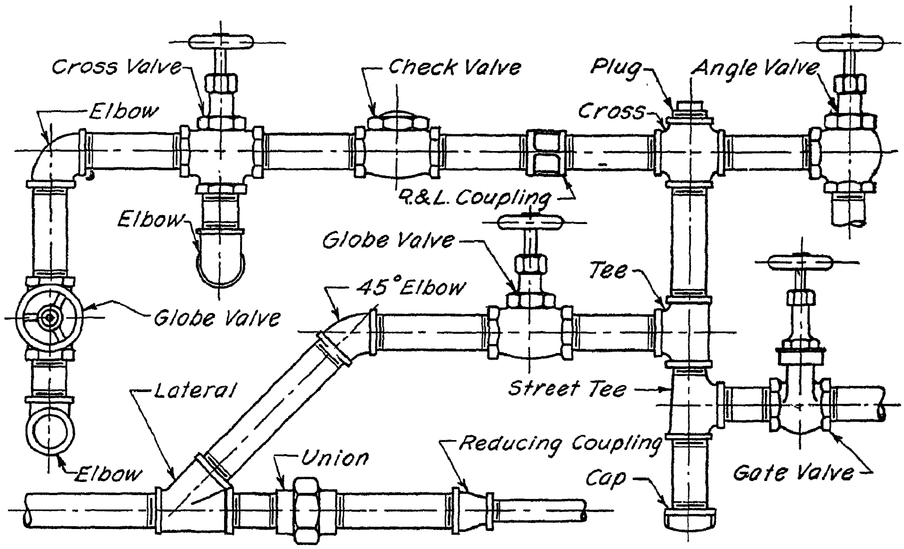


FIG. 571.—Piping drawing, to scale.

valve and *E* a swing check valve permitting flow in one direction. For heavy liquids the ball check valve is preferred. *D* is a globe valve, used for throttling steam or other fluids; *F* is a butterfly valve, opened and closed with a quarter turn, but not steamtight, and used only as a check or damper.

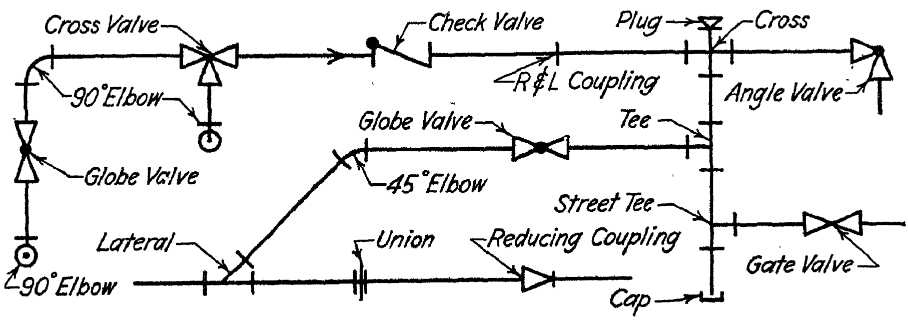


FIG. 572.—Piping drawing, diagrammatic.

247. Piping Drawings.—When drawn to large scale, piping is represented as in Fig. 571. On small-scale drawings or in sketches the fittings are shown by conventional symbols and the runs of pipe by a single line, regardless of the pipe diameters, Fig. 572. The single line should be made heavier than the other lines of the drawing.

The arrangement of views is generally in orthographic projection, Fig. 573 *A*. Sometimes, however, it is clearer to swing all the piping into one plane and make only one "developed view" as at *B*. Isometric and oblique diagrams, used either alone or in conjunction with orthographic or developed make-up drawings, are very often employed in representing piping, as at *C*.

248. Dimensions.—The dimensions on a piping drawing are principally *location* dimensions, all of which are made to center lines, both in single-line diagrams and in double-line representation. Valves and fittings are located by measurements to their centers, and the allowances for make-up left to the pipe fitter. In designing a piping layout, care should be taken to locate valves so that they are easily accessible and have ample clearance at the handwheels. The *sizes* of pipe should be specified by notes telling the nominal diameters, never by dimension lines on the drawing of the pipes. Very complete notes are an important essential of all piping drawings and sketches.

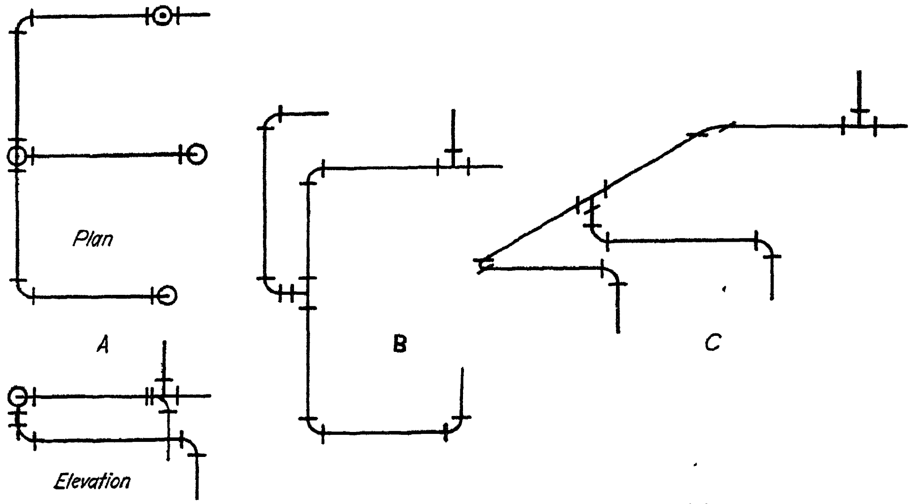


FIG. 573.—Piping in orthographic, developed and pictorial views.

Dimensions for standard pipe and for various fittings are given in the Appendix.

PROBLEMS

1. Pipe Fittings.—Make a complete developed layout of piping (full size), with necessary dimensions and specifications, showing the following: angle valve, globe valve, cross, 90° ell, 45° ell, Y, street tee, tee, screwed union, cap and plug. Place angle valve in one of the upper corners of the sheet. Add extra pipe and nipples, but no extra fittings, to close the system. Use 1½″ pipe and fittings throughout.

2. Pipe Fittings.—In the upper left-hand corner of sheet draw a 2″ tee, (full size). Plug one outlet. In the second, place a 2″ × 1½″ bushing; in remaining outlet use a 2″ close nipple and on it screw a 2″ × 1½″ reducing coupling. Lay out remainder of sheet so as to include the following 1½″ fittings: coupling, globe valve, R&L coupling, angle valve, 45° ell, 90° ell, 45° Y, cross, cap, three-part union, flange union. Add extra pipe, nipples and fittings so the system will close at the reducing fitting first drawn.

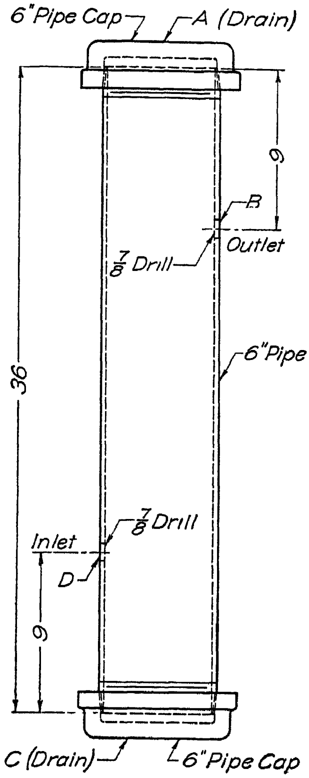


FIG. 574.—Separator.

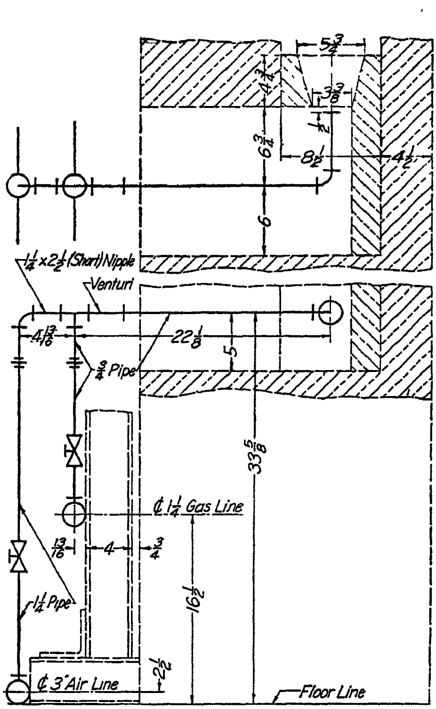


FIG. 575.—Gas-burner installation.

3. Make a one-view drawing of a 1½" globe valve. 8½" × 11" sheet. See Appendix for proportions.

4. Same as Prob. 3 for a 1½" angle globe valve.

5. Same as Prob. 3 for a 1¼" gate valve.

6. Fig. 574. Draw the separator and fittings as specified, arranging them in the order given:

At *A*.—Tap 6" pipe cap for ¼" × 2" nipple; ¼" ell opening to the left; ¼" × 10" pipe; ¼" ell opening downward; ¼" × 24" pipe; ¼" cock; ¼" pipe, length to suit.

At *B* and *D*.—¾" flange, welded; ¾" × 2" nipple; ¾" union; ¾" pipe, length to suit.

At *C*.—Tap for ½" × 2" nipple; ½" × 125# brass globe valve; ½" pipe, length to suit. 11" × 17" sheet; scale 3" = 1'-0".

7. Fig. 575. Make a detail (double-line) piping drawing of the gas-burner installation. Specify fittings and give C.L. dimensions. Use 11" × 17" sheet; scale 3" = 1'-0".

8. Fig. 576. Make a detail (double-line) piping drawing, to suitable scale, of the fuel-oil-burner installation. All pipe and fittings are ¼". Name and specify all fittings. Pipe lengths to suit.

9. Fig. 577. Make a detail (double-line) piping drawing of Grinnell Industrial Heating Unit, Type 90-L, closed return, gravity system. Use C.L. distances and placement of fittings as shown in diagram. 3" supply main; 2" pipe and fittings to unit; ¾" pipe and fittings from unit to return main; 2" return main. Add all necessary notes and dimensions. 11" × 17" sheet; scale 3" = 1'-0".

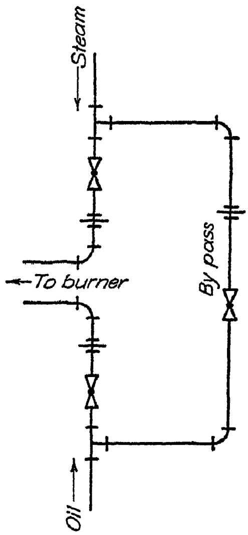


FIG. 576.—Fuel-oil burner installation.

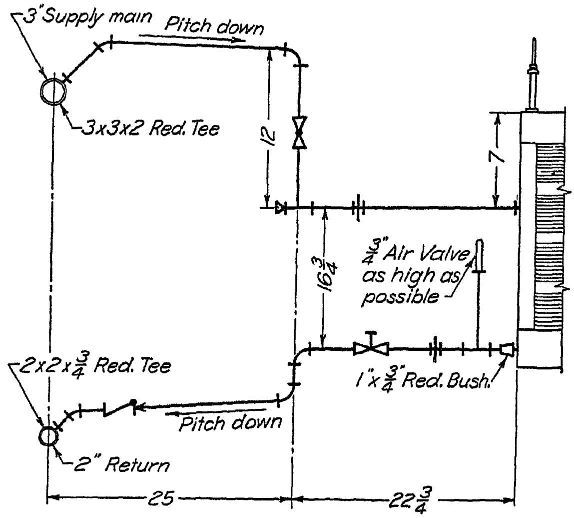


FIG. 577.—Grinnell industrial heating unit.

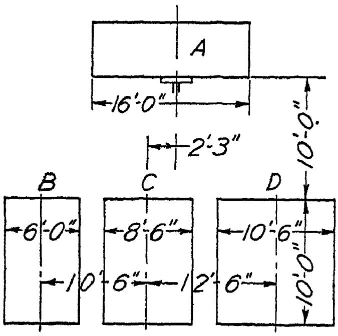


FIG. 578.

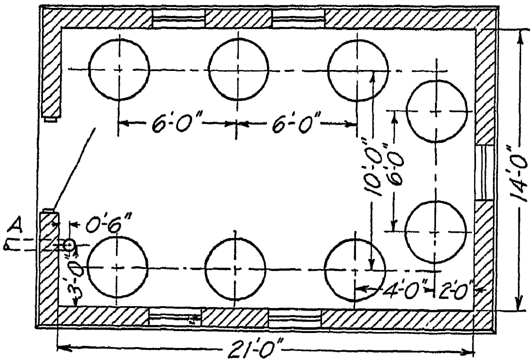


FIG. 579.

10. Fig. 578. *A* is a storage tank for supplying the mixing tanks *B*, *C* and *D* and is located directly above them. The capacities of the mixers are in the ratios of 1, 2 and 3. Design (in one view) a piping system with sizes such that, neglecting frictional losses, the three tanks will fill in approximately the same time. So arrange the piping that any one of the tanks can be cut out or removed for repairs without disturbing the others. Use single-line conventional representation. Dimension to center lines and specify the names and sizes of fittings.

11. Same as Prob. 10 except in the arrangement of the tanks. In plan the tanks *B*, *C* and *D* are placed at the points of an equilateral triangle whose sides are 12 feet long. The center of tank *A* is in line with the centers of *B* and *C*, and 20 feet from the center of *B*, the nearer one. Draw plan and developed elevation of the piping system, with single-line representation. Dimension to center lines and specify fittings.

12. Figure 579 shows the arrangement of a set of mixing tanks. Make an isometric drawing of an overhead piping system to supply water to each tank. Water supply enters the building through a $2\frac{1}{2}''$ main at point *A*, 3 feet below floor level. Place all

pipe 10 feet above floor level, except riser from water main and drops to tanks, which are to end with globe valves 5 feet above floor level. Arrange the system to use as little pipe and as few fittings as possible. Neglecting frictional losses, sizes of pipe used should be such that they will deliver approximately an equal volume of water to each tank if all were being filled at the same time. The pipe size at the tank should not be less than ¾″. Dimension and specify all pipe and fittings.

13. Make a drawing of the system of Prob. 12. Show the layout in a developed view, using double-line conventional treatment. Dimension from center to center and specify all pipe and fittings.

14. Make a list of the pipe and fittings to be ordered for the system of Prob. 12. Arrange the list in a table, heading the columns as below:

Size	Pipe lengths	Valves		Fittings		Material	Remarks (make, kind of threads, etc.)
		Number	Kind	Number	Kind		

15. Make an oblique drawing of a system of piping to supply the tanks in Fig. 579. All piping except risers shall be in a trench 1 foot below floor level. Risers should not run higher than 6 feet above floor level. Other conditions as in Prob. 12.

16. Make a drawing of the system of Prob. 12. Show the layout in a developed view, using single-line conventional treatment. Dimension from center to center and specify all pipe and fittings.

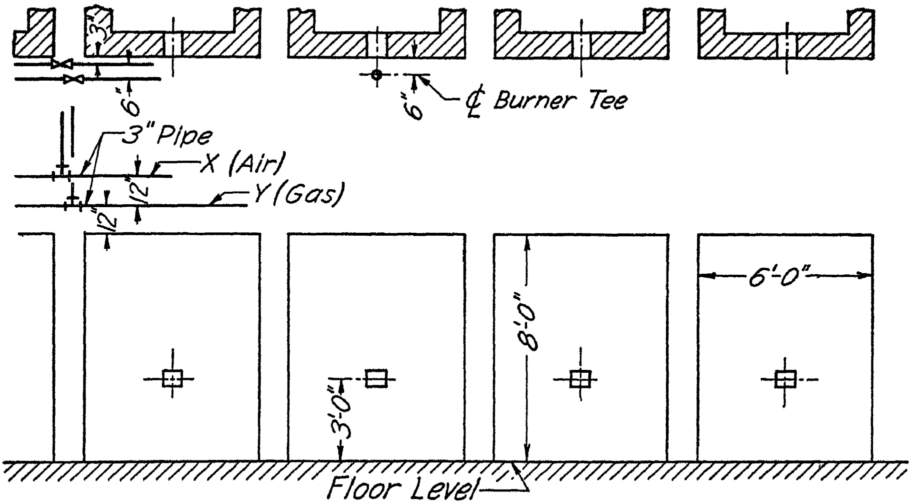


FIG. 580.—Heat-treating furnaces.

17. Figure 580 shows the outline of the right-hand half of a bank of eight heat-treating furnaces. *X* and *Y* are the leadins from the compressed-air and fuel mains. Draw the piping layout, using single-line representation, to distribute the air and fuel to the furnaces. The pipe sizes should be reduced proportionately as the oven leads are taken off. Each tail pipe should be removable without disturbing the other leads or closing down the other furnaces. Dimension the piping layout and make a bill of material for the pipe and fittings.

18. From memory, make a sketch of three kinds of valves.

19. From memory, make a sketch of eight different pipe fittings.

CHAPTER XIV

WORKING DRAWINGS

249. Definition.—A working drawing is a drawing that gives all the information necessary for the complete manufacture or construction of the object represented. It is a technical description of a machine or structure designed for a certain purpose and place and should convey all the facts regarding it so fully and explicitly that no further instruction concerning either manufacture or erection would be required.

The drawing will thus include:

1. The full graphical representation of the shape of each part and its relationship to every other part of the object (*shape description*).
2. The figured dimensions of all parts (*size description*).
3. Explanatory notes giving specifications in regard to materials, finish, heat-treatment, etc.
4. A descriptive title.

Often, particularly in architectural and structural drawing, the notes of explanation and information concerning details of materials and workmanship are too extensive to be included on the drawings and so are made up separately in typed or printed form and called the *specifications*. These are considered as virtually a part of the drawings, the information in them having equal weight and importance. Thus we have the term "drawings and specifications."

250. Classes of Working Drawings.—Working drawings may be divided into two general classes: assembly drawings and detail drawings.

251. Assembly Drawings.—An assembly drawing is, as its name implies, a drawing of the machine or structure put together, showing the relative positions of the different parts. The term "construction drawing" is sometimes used. Its views may be either exterior or sectional.

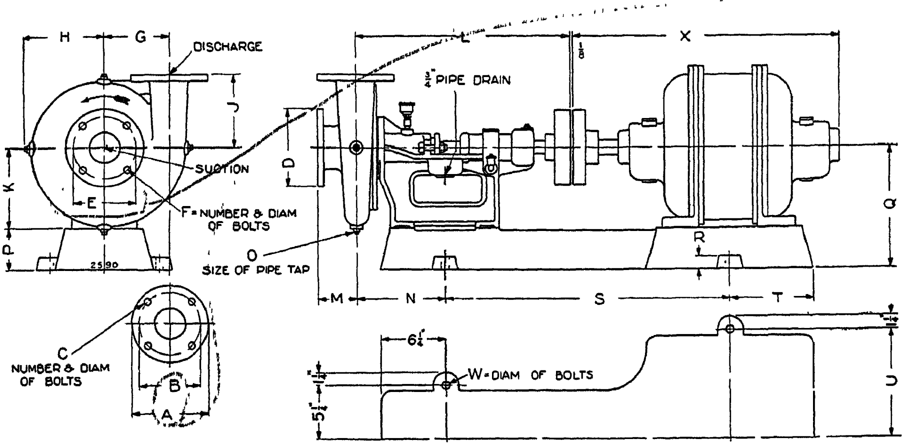
Under the term "assembly drawings" are included preliminary design drawings and layouts, piping plans, unit assembly drawings and final complete drawings used for assembling or erecting the machine or structure.

The *design drawing* is the preliminary layout, full size if possible, on which the scheming, inventing and designing are accurately worked out, after the general ideas have been determined by freehand sketches and calculations. From it the detail drawings of each piece are made.

The *assembly drawing* is in some cases made by tracing from the finished design drawing. Oftener, it is drawn from the design drawing, perhaps

to smaller scale to fit a standard sheet, the draftsman working from the dimensions of the detail drawings. This makes a valuable check on the correctness of the detail drawings and should be done before the details are sent out as finished.

The assembly drawing may give the over-all dimensions and the distances between centers or from part to part of the different pieces, thus fixing the relation of the parts to each other and aiding in the erection of the machine. It should not be overloaded with detail, particularly invisible detail. Unnecessary hidden lines should not be used on any drawing, least of all on an assembly drawing.



CODE WORD	PIPE SIZES DISCH	PIPE SIZES SUCT'N	A	B	C	D	E	F	G	H	J	K	L	M	N	O	P	Q	R	S	T	U	W	X
			DIMENSIONS IN INCHES																					
JAY	$1\frac{1}{2}$"	2"	TAPPED OPENINGS						$5\frac{13}{16}$	$6\frac{7}{8}$	$6\frac{1}{2}$	$7\frac{3}{4}$	$20\frac{3}{8}$	$3\frac{1}{4}$	$8\frac{5}{16}$	$\frac{3}{8}$								
JABBER	2"	$2\frac{1}{2}$"	6	$4\frac{3}{4}$	4-$\frac{5}{8}$	7	$5\frac{1}{2}$	4-$\frac{5}{8}$	$5\frac{29}{32}$	$7\frac{1}{4}$	$6\frac{1}{2}$	$7\frac{3}{4}$	$20\frac{7}{16}$	3	$8\frac{1}{4}$	$\frac{3}{8}$								
JACKET	3"	3"	$7\frac{1}{2}$	6	4-$\frac{5}{8}$	$7\frac{1}{2}$	6	4-$\frac{5}{8}$	$6\frac{1}{4}$	$7\frac{11}{16}$	7	$7\frac{3}{4}$	$20\frac{11}{16}$	$3\frac{3}{4}$	$8\frac{1}{2}$	$\frac{3}{8}$	ABOVE DIMENSIONS DETERMINED BY SIZE OF MOTOR AND BASE USED							
JACK	4"	4"	9	$7\frac{1}{2}$	8-$\frac{5}{8}$	9	$7\frac{1}{2}$	8-$\frac{5}{8}$	$7\frac{11}{16}$	$8\frac{3}{4}$	$7\frac{3}{4}$	$8\frac{13}{16}$	$22\frac{11}{16}$	$4\frac{1}{2}$	10	$\frac{1}{2}$								
JACOBUS	5"	5"	10	$8\frac{1}{2}$	8-$\frac{3}{4}$	10	$8\frac{1}{2}$	8-$\frac{3}{4}$	$8\frac{1}{8}$	$9\frac{1}{8}$	$8\frac{1}{4}$	$8\frac{13}{16}$	$22\frac{15}{16}$	5	$10\frac{1}{4}$	$\frac{1}{2}$								

FIG. 581.—An outline assembly drawing, tabular.

Assembly drawings often have reference letters or numbers designating the different parts. These "piece numbers," sometimes enclosed in circles (called by draftsmen "balloons"), with a leader pointing to the piece, are used in connection with the details and bill of material.

Diagram drawing is the term applied to the foregoing class of assembly drawings, as well as to those made to show piping, wiring, heating, etc.

An outline assembly drawing is used to give a general idea of a machine or structure and contains only the principal dimensions, Fig. 581. When it is made for catalogue or other illustrative purposes, dimensions are often omitted. Shade lines are occasionally used on this class of drawings, and sometimes line shading. See Chap. XXIX.

An assembly working drawing, showing fully the construction of each piece as well as the relative positions, may be made for a simple machine.

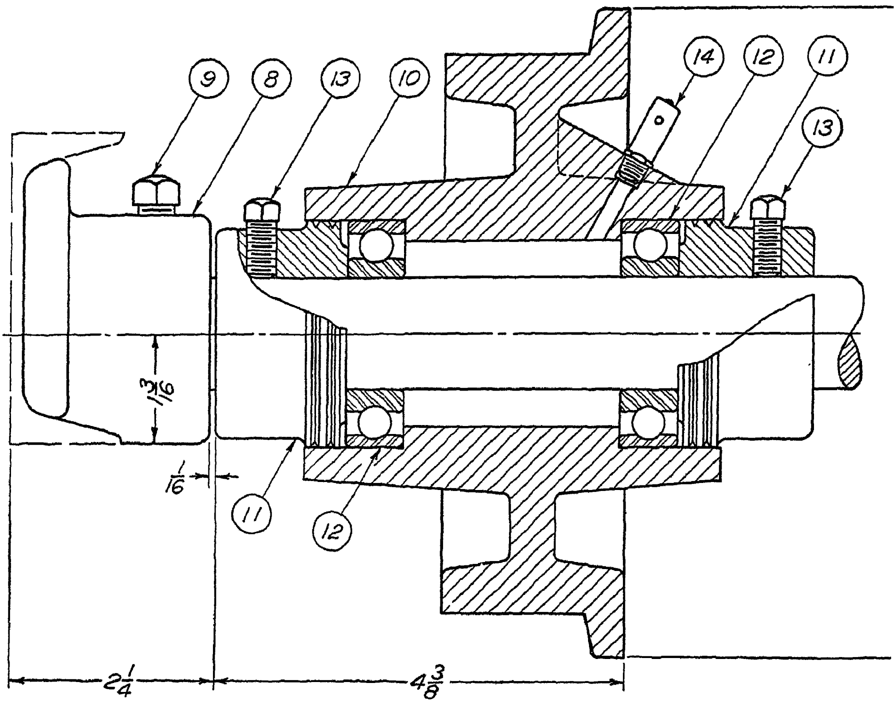


Fig. 582.—A unit assembly drawing.

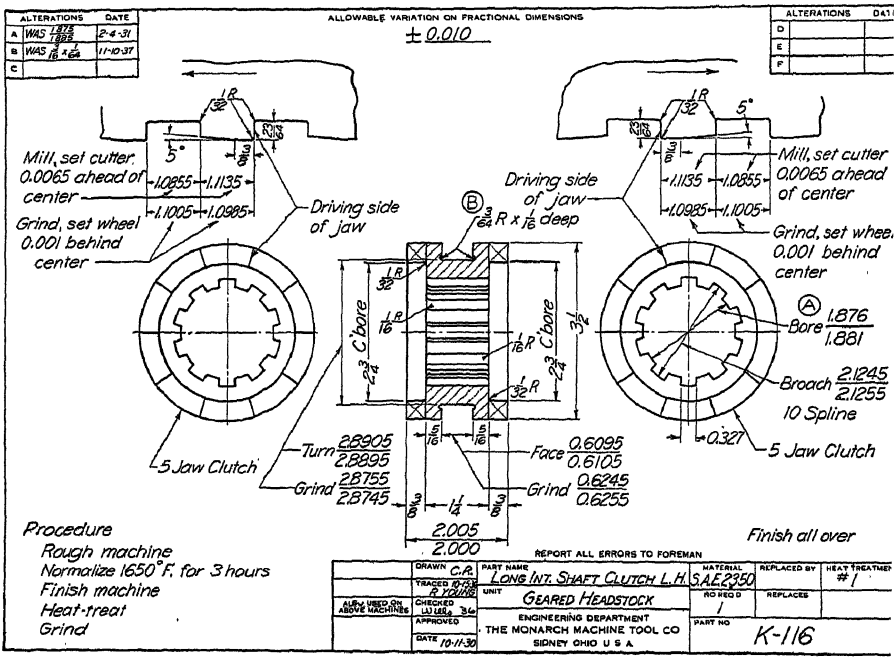


Fig. 583.—A detail drawing.

A unit assembly drawing, or subassembly, Fig. 582, is a drawing of a related group of parts, used in more complicated machinery, instead of, or together with, separate details of each part. Thus there would be a unit assembly of such parts as rear axle and differential gear train; of transmission gearbox; of lathe headstock; etc.

252. Detail Drawings.—A detail drawing is the drawing of a separate piece, giving a complete and exact description of its form, dimensions and construction. A successful detail drawing will tell the workman *simply* and *directly* the shape, size, material, and finish of each part, what shop operations are necessary, what limits of accuracy must be observed, and how many of each are wanted. Figure 583 is a detail drawing of a small piece, illustrating the use of decimal dimensions.

The *grouping* of the details on the sheet is entirely dependent upon the requirements of the shop system. In a very simple machine and if only one or two are to be built (as, for example, in jig and tool work), all the details may perhaps be grouped on a single sheet. The detailed pieces should be set in the same position as on the assembly and, to facilitate reading, placed as nearly as possible in natural relationship. Often parts of the same material or character are grouped together, for example, forgings on one sheet and special bolts and screws on another.

In large production the accepted and best system is to have each piece, no matter how small, on a separate sheet.

253. Plant Layouts.—In laying out the positions of machine tools and equipment in a plant, generally a drawing of the building is made and the machines are located by making scale drawings of them, cutting them out, and shifting them around on the building plan to get the best arrangement. When the final positions are decided upon, a drawing is made showing the machines and the "route lines" for materials and products. The Ford Motor Company now saves some of the drawing time required for this work by making the building drawing on beaverboard, attaching the machine cutouts to the drawing with a paper-stapling machine and then photostating the complete assembly. The photostat is made to half the scale of the "master board" and is used as any plant layout drawing would be. The master boards are filed away in special cases so that when changes are necessary the machines may be relocated, and a new photostat made.

254. Tabular Drawings.—A tabular drawing, either assembly or detail, is one on which the dimension lines are given reference letters, an accompanying table on the drawing listing the corresponding dimensions for a series of sizes of the machine or part, thus making one drawing serve for the range covered. Some companies manufacturing parts in a variety of sizes use this tabular system of size description, but a serious danger with it is the possibility of misreading the table. It is not recommended for quantity production.

255. Standard Drawings.—To avoid the difficulties experienced with tabular drawings, some companies are now making a "standard drawing" complete except for the actual figured dimensions. This drawing is reproduced by offset printing or black-and-white reproduction on vellum paper, and the reproductions are dimensioned separately for the various sizes of parts. This method gives a separate, complete drawing for each size of part, and when a new size is needed the drawing is easily and quickly made. Figure 584 shows a standard drawing, and Fig. 585 the completed working drawing.

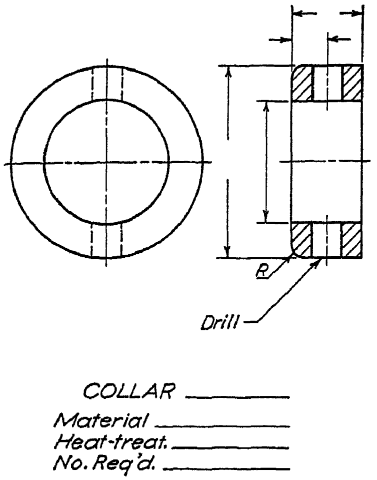


FIG. 584.—A standard drawing.

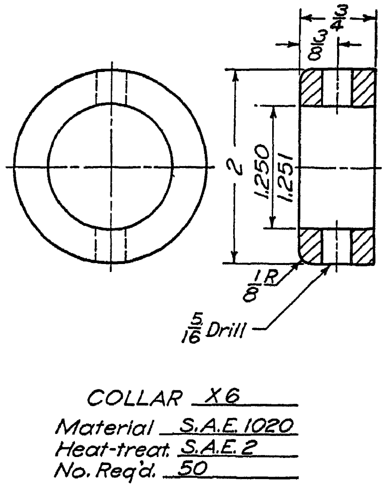


FIG. 585.—A standard drawing filled in.

256. Set of Drawings.—A complete *set* of working drawings consists of detail sheets and assembly sheets, the former giving all necessary information for the manufacture of each individual piece, and the latter showing the parts assembled as a finished unit or machine. The set includes the bill of material and may also contain special drawings for the purchaser, such as foundation plans or oiling diagrams.

257. Style.—There is a *style* in drawing, just as there is in literature, which in one way indicates itself by the ease of reading. Some drawings stand out, while others which may contain all the information are difficult to decipher. Although dealing with mechanical thought, there is a place for some artistic sense in mechanical drawing. The number, selection and disposition of views, the omission of anything unnecessary, ambiguous or misleading, the size and placement of dimensions and lettering, and the contrast of lines are all elements concerned in the *style*.

258. Choice of Views.—Although pictorial drawings are used to some extent in special cases, the basis of all working drawing is orthographic projection. Thus, to represent an object completely, at least two views are necessary, often more. The only general rule is, *make as many views as are*

necessary to describe the object clearly, **and no more.** Instances may occur in which the third dimension is so evident as to make one view sufficient, as, for example, in the drawing of a shaft or bolt. In other cases perhaps a half-dozen views might be required to describe a piece completely.

As previously stated, select for the front view the face showing the largest dimension, preferably the obvious front of the object when in its functioning position, and then decide what other views are necessary. A vertical cylindrical piece, for example, would require only a front and a top view; a horizontal cylindrical piece only a front and a side view. Determine which side view to use, or whether both are needed. The one with the fewest hidden lines should be preferred. See whether an auxiliary view or a note will save one or more other views, and whether a section will be better than an exterior view. One statement may be made with the force of a rule: *If anything in clearness can be gained by violating a principle of projection violate it.*

Paragraphs 140 to 144, Chap. IX, give a number of examples of conventions that are in violation of theoretical representation but are in the interest of clearness. The draftsman must remember that his responsibility is to the reader of the drawing and that he is not justified in saving himself any time or trouble at the expense of the drawing by making it less plain or easy to read. The time so saved by the draftsman may be lost to the company a hundredfold in the shop, where the drawing is used not once but repeatedly.

259. Making a Working Drawing—Order of Penciling.—After the scheming, inventing and calculating have been done, the order of procedure is:

First, lay off a sheet to standard size, with the excess paper to the right, as a convenient space for making sketches and calculations, and block out the space for the title. Or lay off the standard size very lightly and, after the drawing is finished, shift the border to balance the sheet.

Second, decide what scale is to be used, choosing one large enough to show all dimensions without crowding, and plan the arrangement of the sheet by making a little preliminary freehand sketch, estimating the space each view will occupy, and placing the views to the best advantage for preserving if possible a balance in the appearance of the sheet.

Third, draw the center lines for each view and on these "block in" the views by laying off the principal dimensions and outlines, using **light, sharp, accurate** pencil lines. Center lines are drawn for the axes of symmetry of all symmetrical views or parts of views. Thus every cylindrical part should have a center line—the projection of the axis of the piece. Every circle should have two center lines intersecting at its center.

Fourth, finish the projections, putting in last the minor details such as fillets, rounded corners, etc. The different views should be carried on together, projecting a characteristic shape as shown on one view to the other views, not finishing one view before starting another.

Fifth, draw all necessary dimension lines, then put in the dimensions.

Sixth, draw guide lines for the notes and then letter them.

Seventh, lay out the title.

Eighth, check the drawing carefully.

As an aid in tracing, either in pencil or in ink, the finished outline or parts of it may if necessary be brightened by running over a second time with the pencil. The overrunning lines of the constructive stage should not

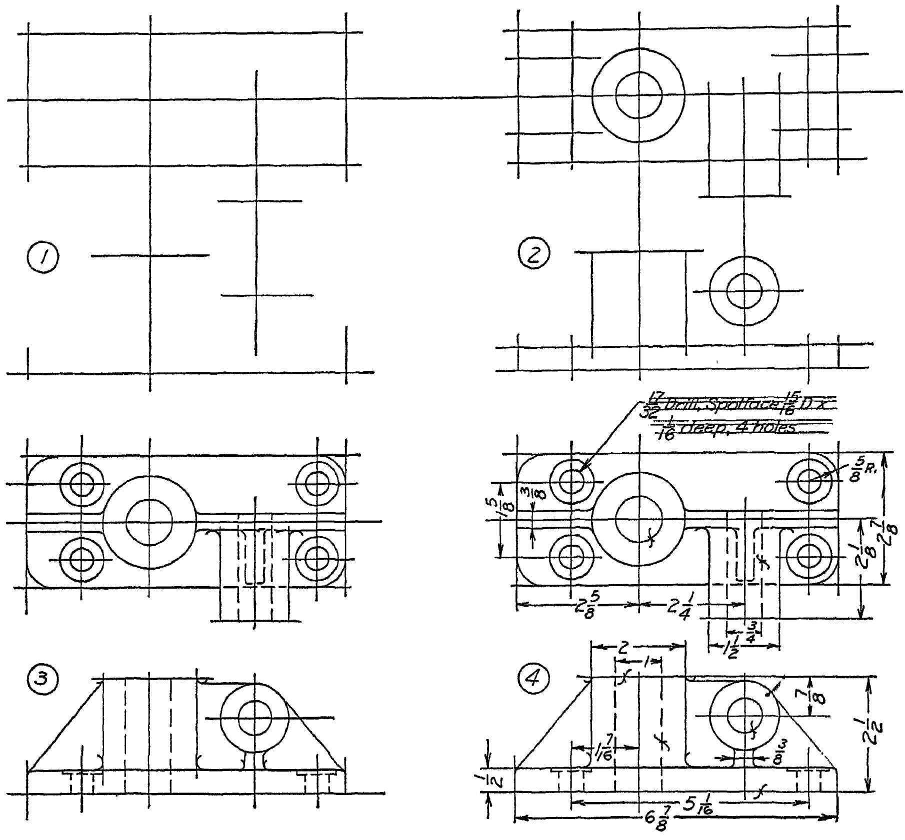


FIG. 586.—Order of penciling.

be erased before tracing or inking. These extensions are often convenient in showing the stopping points. All unnecessary erasing should be avoided as it abrades the surface of the paper so that it catches dirt more readily.

As an aid in stopping tangent arcs in inking it is desirable to mark the tangent point on the pencil drawing with a short piece of the normal to the curve at the point of tangency. Figure 586 illustrates the stages of penciling.

260. Tracing.—Working drawings almost always go to the shop in the form of blueprints or black-line prints, printed from tracings made either in

ink on tracing cloth or in pencil on tracing paper or drawn directly on pencil cloth or translucent bond paper. The beginner should read Chap. XXVIII carefully before starting a tracing on cloth, noticing that the cloth is to be tacked down smoothly with the dull side up, prepared by chalking and tearing off the selvage, and noticing also that no view should be left overnight with only part of its lines traced.

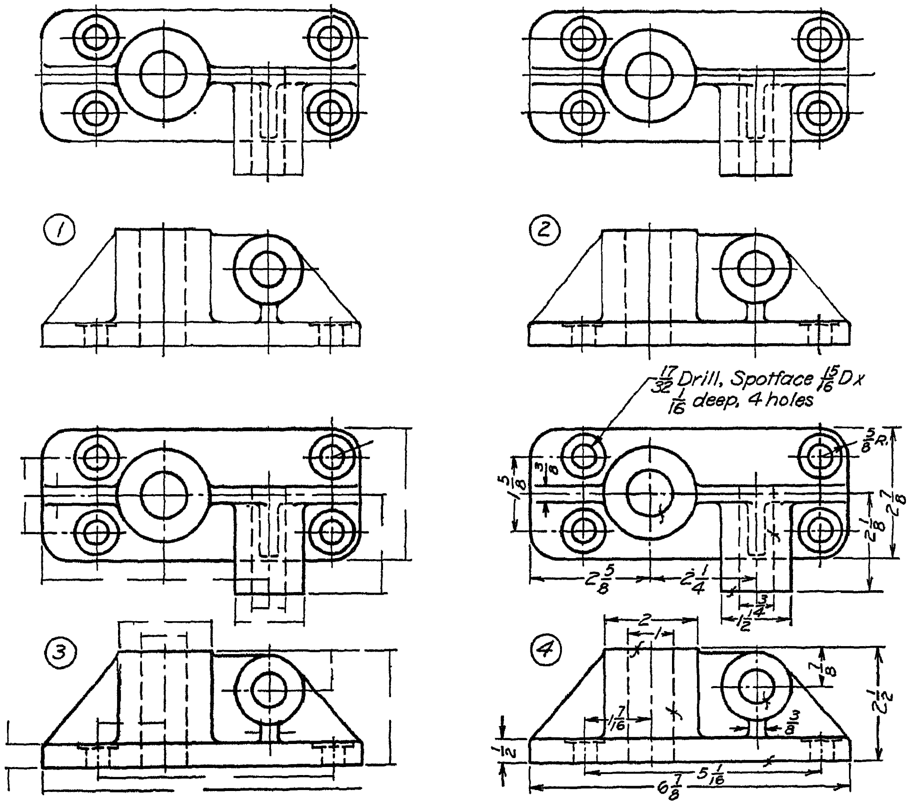


FIG. 587.—Order of inking.

261. Order of Inking.—*First,* ink all full-line circles, beginning with the smallest, then circle arcs.

Second, ink dotted circles and arcs in the same order as full-line circles.

Third, ink any irregular curved lines.

Fourth, ink straight full lines in this order: horizontal, vertical and inclined.

Fifth, ink straight dotted lines in the same order.

Sixth, ink center lines.

Seventh, ink extension and dimension lines.

Eighth, ink arrowheads and dimensions.

Ninth, section-line all areas representing cut surfaces.

Tenth, letter notes and titles. (On tracings draw pencil guide lines first.)

Eleventh, ink the border.

Twelfth, check the inked drawing.

Figure 587 shows the stages of inking.

262. Checking.—Before being sent to the shop a working drawing is carefully checked for errors and omissions. A first check of the pencil drawing is made by the chief designer, who knows the price at which the machine is to be made and checks the design for soundness and economy, sees if existing patterns for any parts can be used, checks for adequate lubrication, for correct representation and other points in the list following.

When the drawing is finished it is gone over by an experienced checker, who in signing his name to it becomes responsible for any errors. This is the final "proofreading" and cannot be done by the one who has made the drawing nearly so well as by another person. In small offices all the work is checked by the chief draftsman, and draftsmen sometimes check each other's work; in large drafting rooms one or more checkers who devote all their time to this kind of work are employed. All notes, computations and checking layouts should be preserved for future reference.

Students may gain experience in this work by checking each other's drawings.

To be effective, checking must be done in an absolutely systematic way and with thorough concentration.

263. To check a drawing, each of the following items[1] should be gone through separately, the checker allowing nothing to distract his attention from it. As each dimension or feature is verified, a check mark should be placed on or above it and corrections indicated with soft or colored pencil.

1. Put yourself in the position of those who are to read the drawing and find out if it is easy to read and tells a straight story. Always do this before checking any individual features; in other words, before you have had time to become accustomed to the contents.
2. See that each piece is correctly designed and illustrated, and that all necessary views are shown but none that are not necessary.
3. Check all the dimensions by scaling and, where advisable, by calculation also. Preserve the calculations.
4. See that dimensions for the shop are given as required by the shop, and that the shop is not left to do any adding or subtracting in order to get a needed dimension.
5. Check for tolerances. See that they are neither too "fine" nor too "coarse" for the particular conditions of the machine, so as neither to increase unnecessarily the cost of production nor, on the other hand, to impair accuracy of operation or duplication.
6. Go over each piece and see that finishes are properly specified.
7. See that every specification of material is correct and that all necessary ones are given.

[1] Adapted from Follows' *Dictionary of Mechanical Drawing*.

8. Look out for "interferences." This means that each detail must be checked with the parts that will be adjacent to it in the assembled machine to see that proper clearances have been allowed.
9. When checking for clearances in connection with a mechanical movement, lay out the movement to scale, figure the principal angles of motion and see that proper clearances are maintained in all positions, drawing small mechanisms to double size or larger.
10. See that all the small details: screws, bolts, pins, keys, rivets, etc., are standard and that, where possible, stock sizes have been used.
11. Check every feature of the title, or record strip, and bill of material.
12. Review the drawing in its entirety, adding such explanatory notes as will increase its efficiency.

264. The Bill of Material.—A bill of material is a tabulated statement, placed on a separate sheet, in the case of quantity production, or on the drawing in other cases, as illustrated in Fig. 676. This table gives the piece number, name, quantity, material, stock size of raw material and sometimes the weight of each piece. A final column is usually left for remarks.

The blank ruling for a bill of material should not be crowded. Lines should never be spaced closer than ¼ inch; $\frac{5}{16}$ or ⅜ inch is better, with the height of the lettering not more than half the space and centered between lines. Instead of being lettered, bills of material are frequently typed on forms printed on thin paper. Intensifying the impression by carbon paper on the back increases the opacity of the typing, and a clearer blueprint will result.

265. Title.—The title of a working drawing is usually boxed-in in the lower right-hand corner, the size of the space varying with the size of the drawing. For 11″ × 17″ sheets the space reserved may be about 3 inches long; for 17″ × 22″ sheets, 4 or 4½ inches, and for 22″ × 34″ sheets, 5 or 5½ inches.

Contents of Title.—In general the title of a machine drawing should contain:

1. Name of machine.
2. General name of parts (or simply "details").
3. Name of purchaser, if special machine.
4. Manufacturer (company or firm name and address).
5. Date (usually date of completion of tracing).
6. Scale or scales; required on assembly drawings, sometimes omitted from fully dimensioned detail drawings.
7. Drafting-room record: names or initials of draftsman, tracer, checker, approving chief draftsman, or other authority, each with date; and space for record of changes and revisions.
8. Number of drawing and of the order if special design. The filing number (which in detail drawings should be the same as the piece number) is often repeated in the upper left-hand corner upside down for convenience in case the drawing should be reversed in the drawer.

Form of Title.—Every drafting room has its own standard form for titles. In large offices the blank form is often printed in type on the tracing paper or cloth. Figures 588 and 589 are characteristic examples.

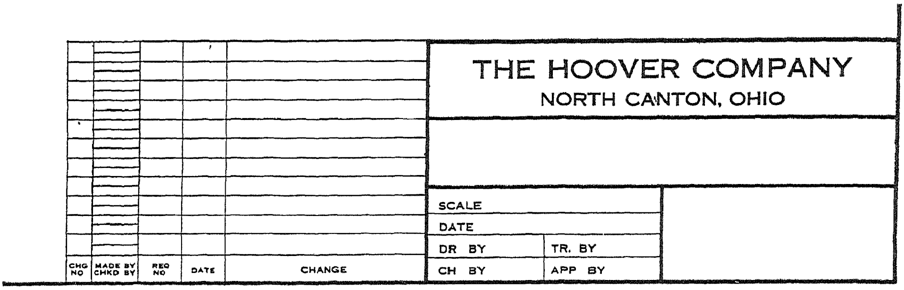


Fig. 588.—A printed title form.

A form of title that is used to some extent is the *record strip*, a strip marked off entirely across either the lower part or right end of the sheet, containing the information required in the title, and space for the record of

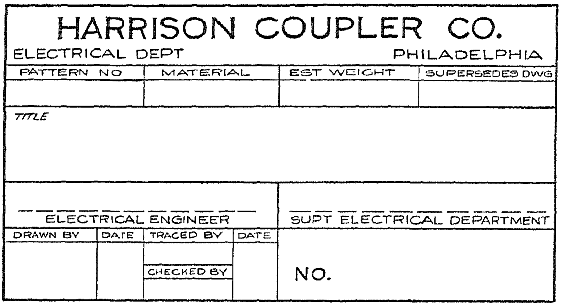


Fig. 589.—A printed title form.

orders, revisions, changes, etc., which should be noted, with date, as they occur. Figure 590 illustrates one form.

It is sometimes desired to keep the records of orders and other private information on the tracing but not to have them appear on the print. In

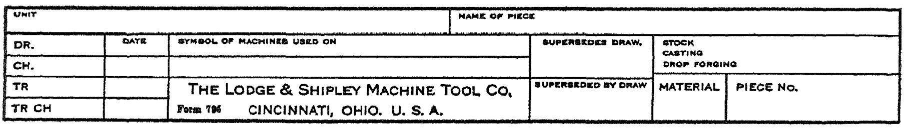


Fig. 590.—A narrow strip title.

such cases a record strip is put outside the border and trimmed off the print before sending it out.

To Draw a Title.—The title should be lettered freehand in single-stroke capitals, either vertical or inclined but not both styles in the same

title. Write out the contents on a separate piece of paper, then refer back to paragraph 44 where full instructions have been given.

266. Commercial Practice.—In commercial drafting *accuracy* and *speed* are the two requirements. The drafting room is an expensive department, and time is thus an important element. The draftsman must therefore have a ready knowledge not only of the principles of drawing but of the conventional methods and abbreviations and of any device or system that will save time without sacrificing clearness.

The usual criticism of the student by the employer is the result of the former's lack of appreciation of the necessity for *speed.*

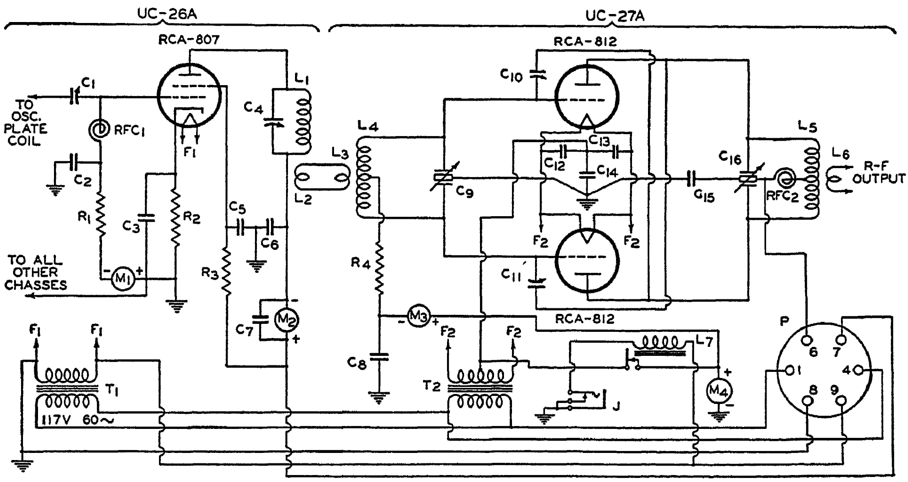


FIG. 591.—Schematic diagram of PM transmitter final amplifier unit. (*Courtesy of RCA.*)

267. Chemical Engineering Drawing.—The study of drawing in preparation for chemical engineering involves all the basic principles considered in this and previous chapters. The chemical engineer should be informed on piping and on the various forms of equipment used in industrial chemistry, such as mixing, grinding, filtering, drying and conveying machinery.

268. Electrical Engineering Drawing.—Electrical engineers need the same basic equipment in the language of drawing as do mechanical or other engineers. In its application in their profession it may be divided into two general classes: working drawings, as of electrical machinery, and diagrammatic or symbolic drawings, such as wiring diagrams, etc.

In electrical working drawings the principles and conventions of this chapter are all applicable. Figure 690 is an example of an erection working drawing.

Diagrammatic drawings, using conventional symbols for electrical connections and equipment, form an important class of electrical drawings. Electrical symbols, wiring symbols and radio symbols are given in the Appendix.

An example of a diagrammatic drawing is shown in Fig. 591. A group of problems on electrical drawing, including electrical equipment, switchboards, motors, wiring and radio are included in Probs. 115 to 128.

PROBLEMS

269. The first part of any working-drawing problem consists of the selection of views, the choice of suitable scales, and the arrangement of the sheet. In classwork a preliminary sketch layout should be submitted for approval before the drawing is commenced.

The problems following are designed to cover the points explained in the text, and their division into groups will suggest a selection of one or more from each group in making up a course. They may be drawn on 11″ × 17″ or 17″ × 22″ sheets.

In dimensioning these problems the principles given in Chap. XI should be followed carefully. Before applying finish marks, study the problem to determine which surfaces should be so marked. On parts which are to fit accurately, the class of fit is to be assumed or assigned, and limit dimensions are to be figured from the nominal sizes given, using the ASA tables of allowances and tolerances in the Appendix. The illustration for the problem is to be taken as the preliminary sketch from which to make the actual working drawing for the shop. Because of restricted space the illustrations are often crowded; do not, therefore, follow them as examples of good spacing or of the best placing of dimensions.

Group I. Exterior Detail Drawings.
Probs. 1 to 11, Figs. 592 to 602.

Group II. Working Drawings in Section.
Probs. 12 to 22, Figs. 603 to 613.

Group III. Auxiliary View Drawings.
Probs. 23 to 42, Figs. 614 to 622 and 347 to 357.
Refer to Chap. VIII for shape description involving auxiliary views.

Group IV. Double Auxiliaries.
Probs. 43 to 47, Figs. 623, 358, 360, 361, 363. Refer to pages 135 and 136.

Group V. Special Representation.
Probs. 48 to 56, Figs. 624 to 632. Refer to pages 154 to 159.

Group VI. Small Assembly Drawings from Details.
Probs. 57 to 60, Figs. 633 to 636.

Group VII. Details from Assembly Drawings.
Probs. 61 to 78, Figs. 637 to 654.

Group VIII. Checking Studies.
Probs. 79 to 81, Figs. 655 to 657.

Group IX. Assembly and Detail Drawings.
Probs. 82 to 114, Figs. 658 to 682.

Electrical Problems.
Probs. 115 to 128, Figs. 683 to 690.

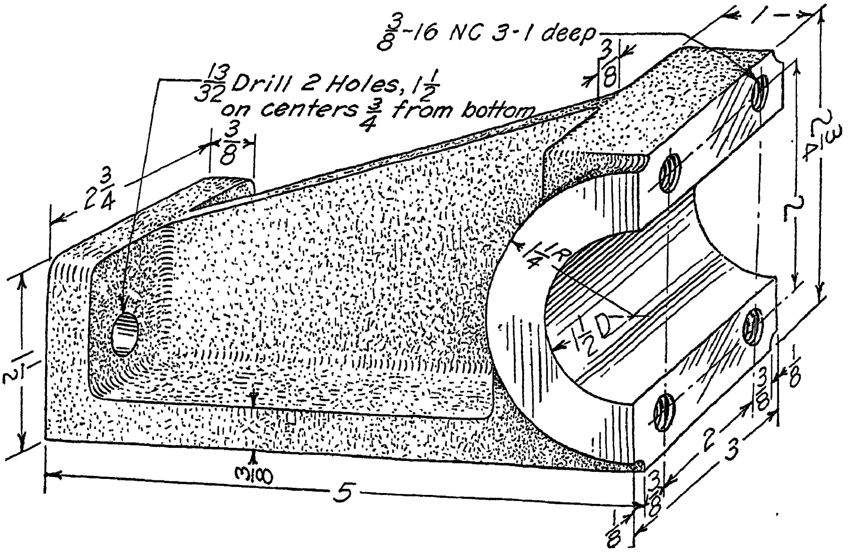


Fig. 592.—Support bearing.

Group I. Exterior Detail Drawings.

1. Fig. 592. Working drawing of support bearing. Three views, full size.
2. Fig. 593. Working drawing of centering-yoke base. Three views, full size.

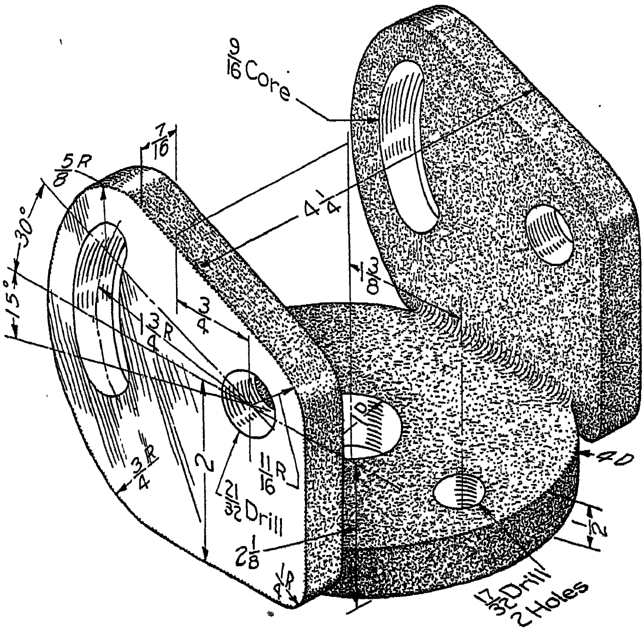


Fig. 593.—Centering yoke base.

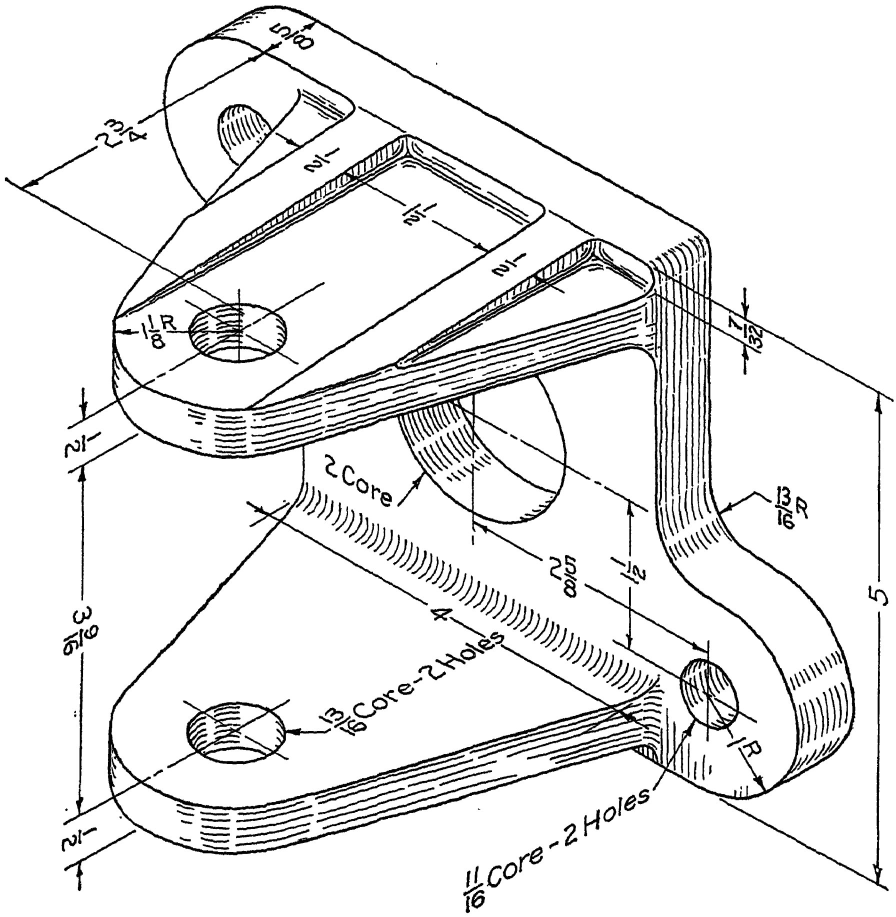


FIG. 594—Drawbar pivot.

3. Fig. 594. Working drawing of drawbar pivot. Scale, $\frac{3}{4}''$ = 1 inch.
4. Fig. 595. Working drawing of steady-rest jaw. Full size.

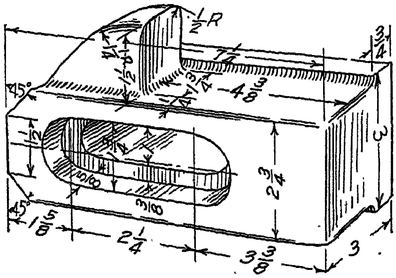


FIG. 595.—Steady rest jaw.

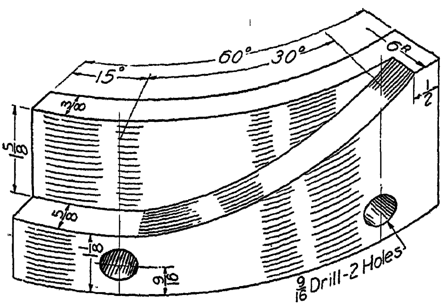


FIG. 596.—Elevating cam.

5. Fig. 596. Working drawing of elevating cam. The cam follower has a uniform rise of $1\frac{5}{8}''$ in a 60-degree movement of the cam. The front view of the inclined surface

can be found by dividing the 6″ radius arc and the rise into the same number of equal parts. In this case 8 would be convenient.

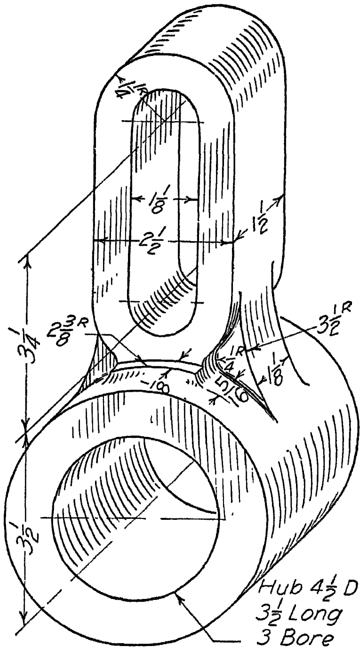


FIG. 597.—Compound-gear arm.

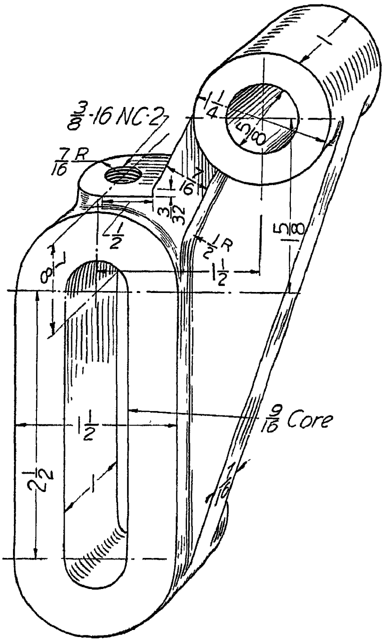


FIG. 598.—Fan bracket.

6. Fig. 597. Working drawing of compound-gear arm.
7. Fig. 598. Working drawing of fan bracket.
8. Fig. 599. Working drawing of adjustable base.

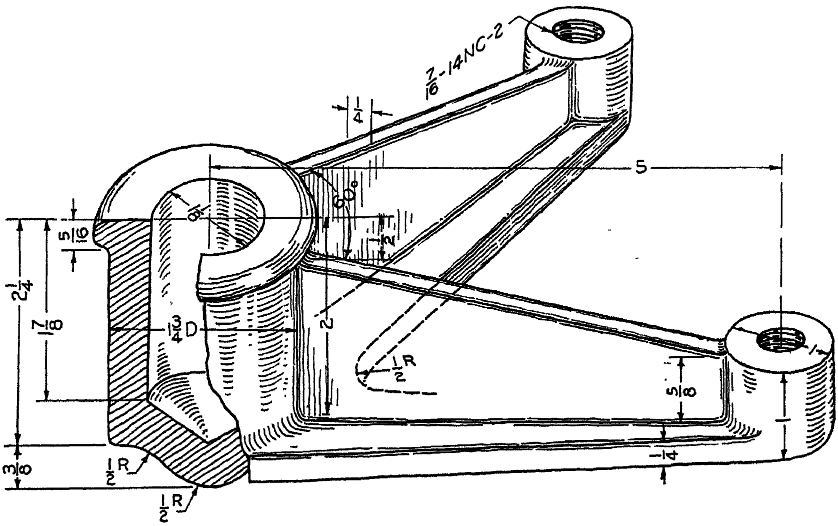


FIG. 599.—Adjustable base.

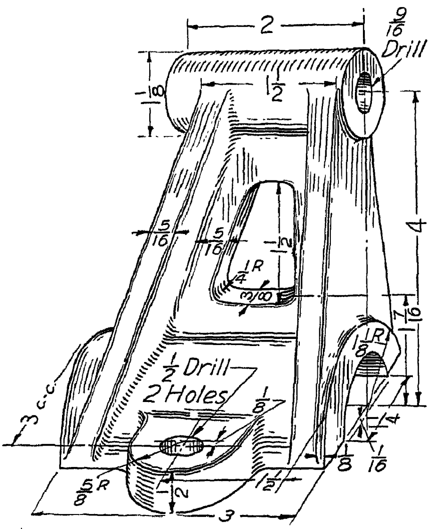


FIG. 600.—Friction shaft bearing.

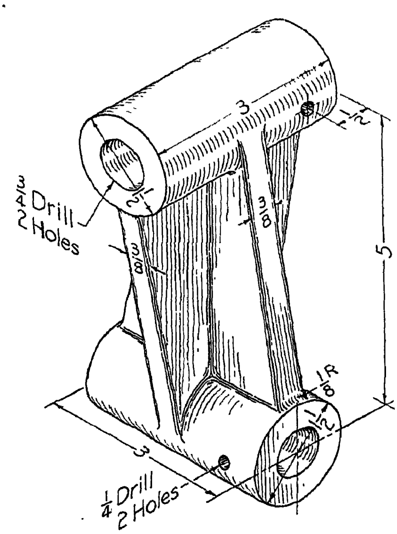


FIG. 601.—Crossover link.

9. Fig. 600. Working drawing of friction shaft bearing.
10. Fig. 601. Working drawing of crossover link.
11. Fig. 602. Working drawing of bed bracket.

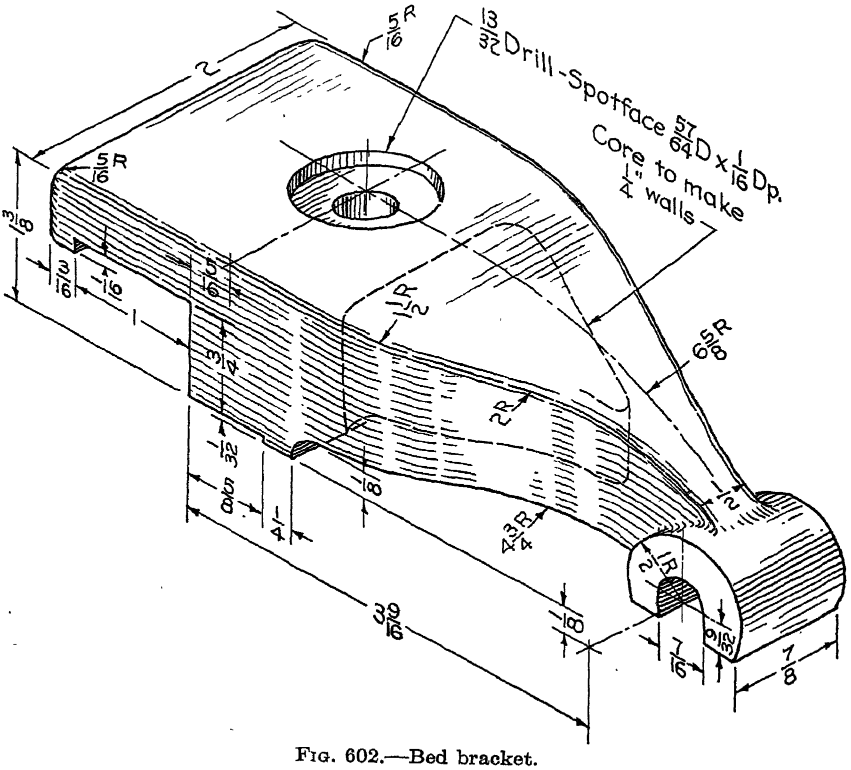


FIG. 602.—Bed bracket.

Group II. Working Drawings in Section.

12, 13, 14, 15, 16. Figs. 603 to 607. Make complete working drawings with necessary sectional views.

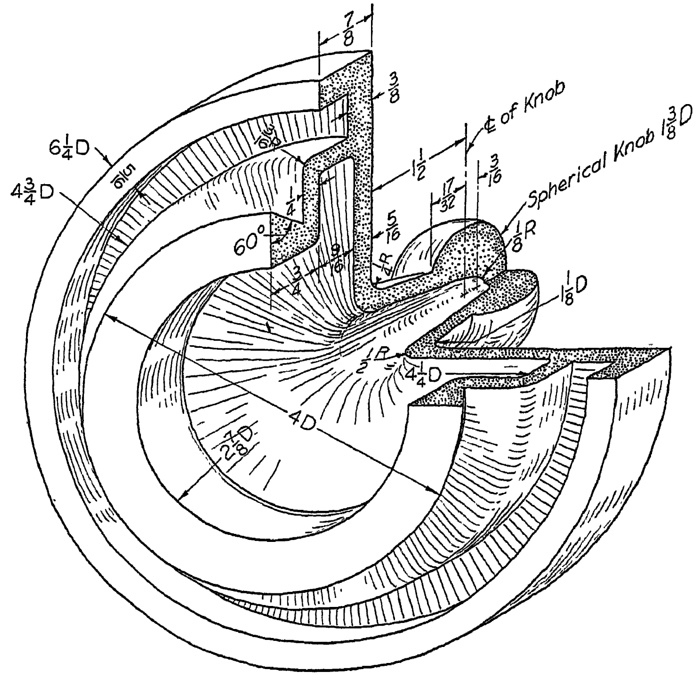


FIG. 603.—Valve seat.

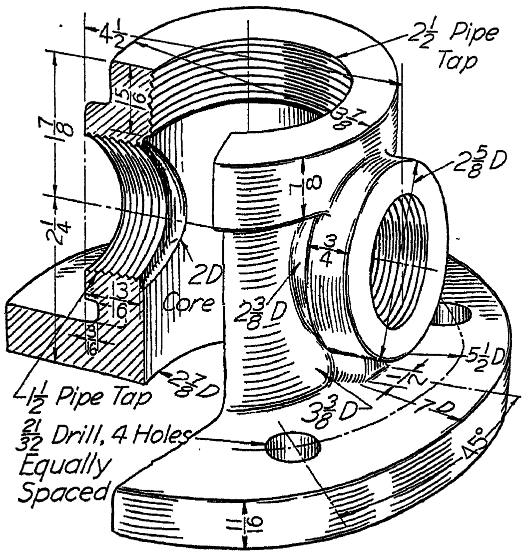


FIG. 604.—Blow-off cross.

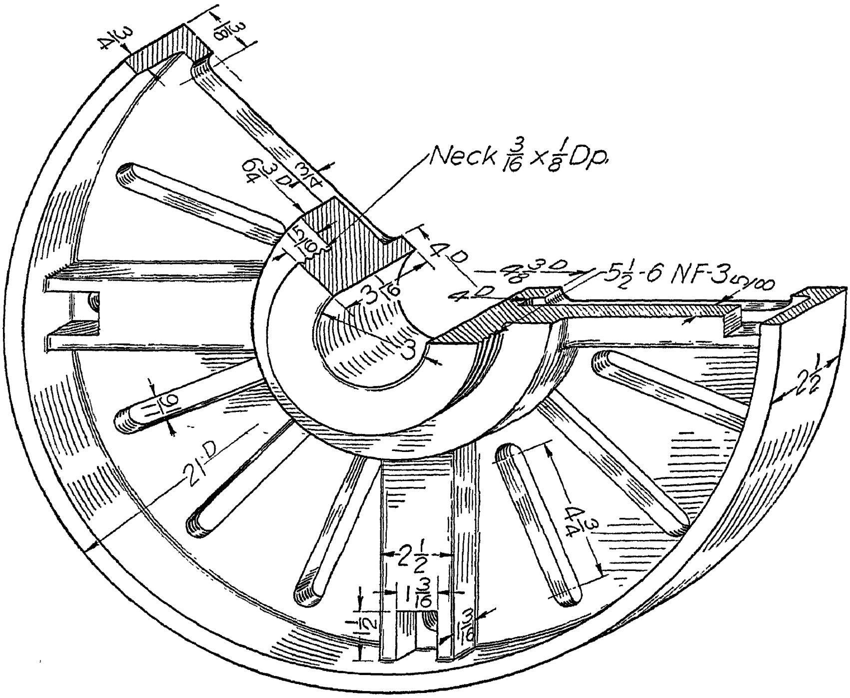


FIG. 605.—Face plate.

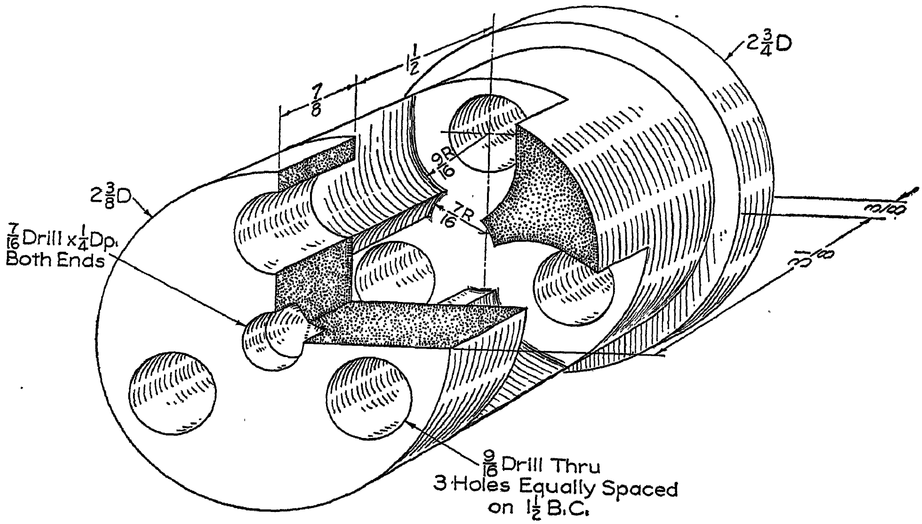


FIG. 606.—Spindle carrier.

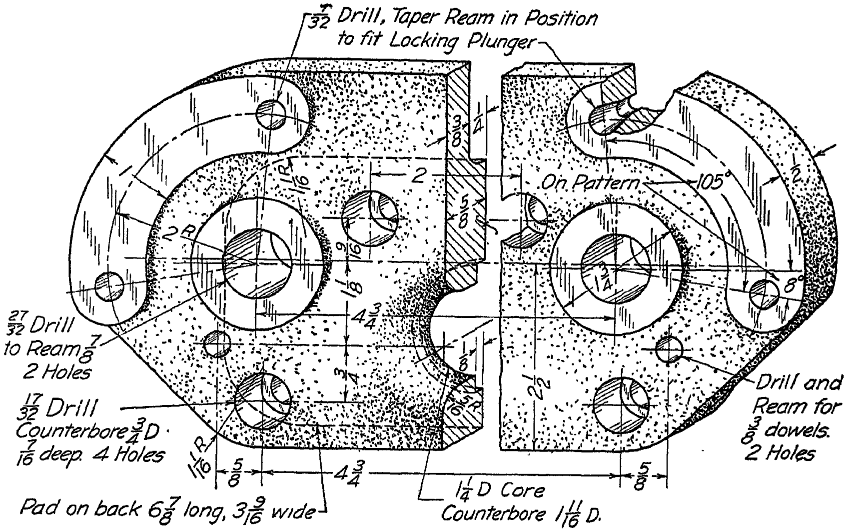


FIG. 607.—Gear shifter bracket.

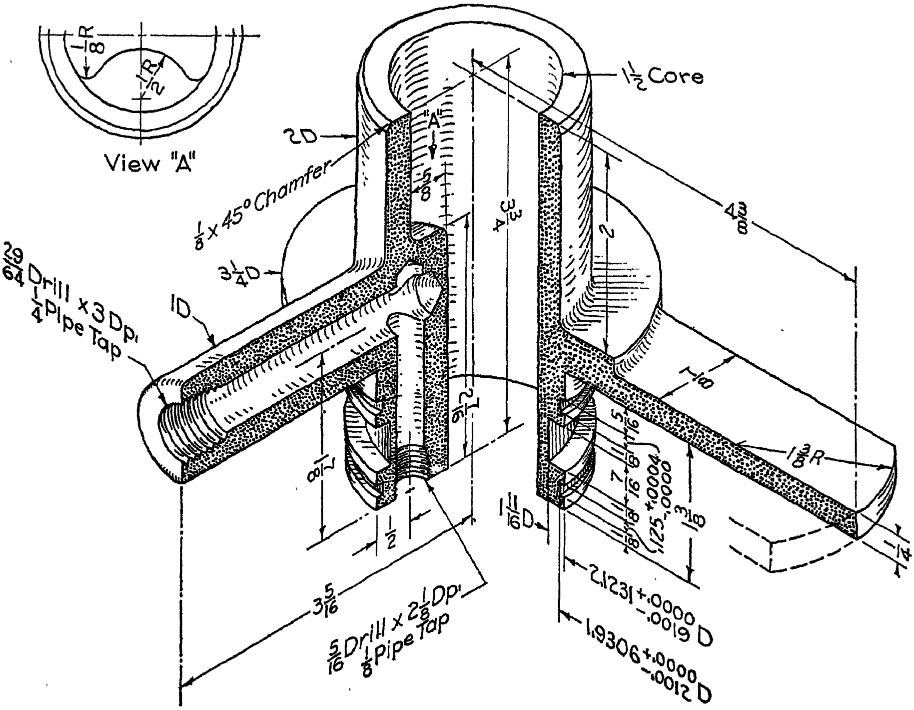


FIG. 608.—Supply head.

17. Fig. 608. Working drawing of supply head.

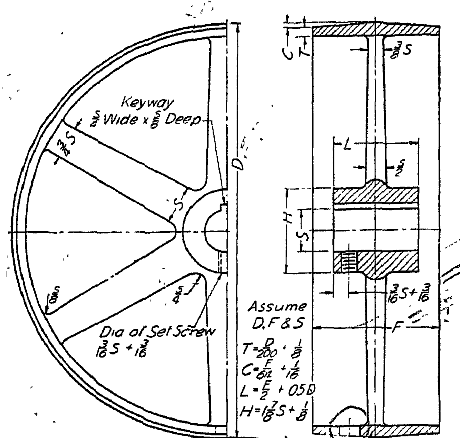


Fig. 609.—Pulley.

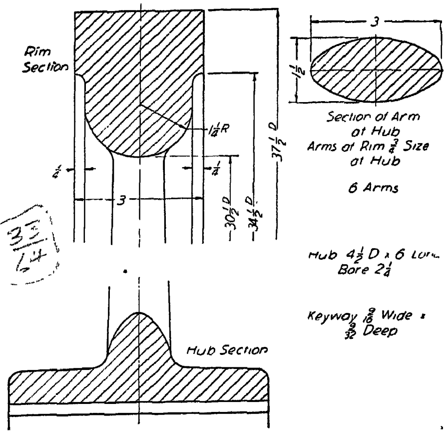


Fig. 610.—Flywheel.

18. Fig. 609. Working drawing of pulley. Suggested sizes: *A*, 10″ diam., 3″ face, 1″ bore; *B*, 12″ diam., 3¼″ face, 1⅛″ bore; *C*, 14″ diam., 3½″ face, 1¼″ bore; *D*, 16″ diam., 3¾″ face; 1⅜″ bore; *E*, 18″ diam., 4″ face, 1½″ bore; *F*, 20″ diam., 4½″ face 1⅝″ bore; *G*, 24″ diam., 5″ face, 1¾″ bore.

19. Fig. 610. Working drawing of cast-iron flywheel. Calculate weight of rim.

20. Fig. 611. Make detail drawings of eccentric and strap.

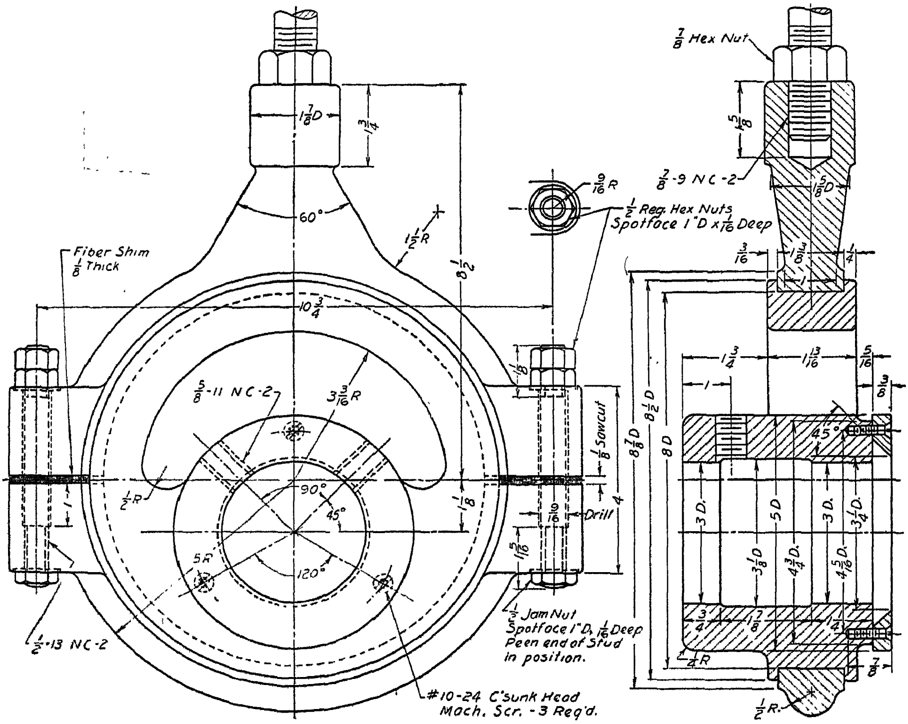
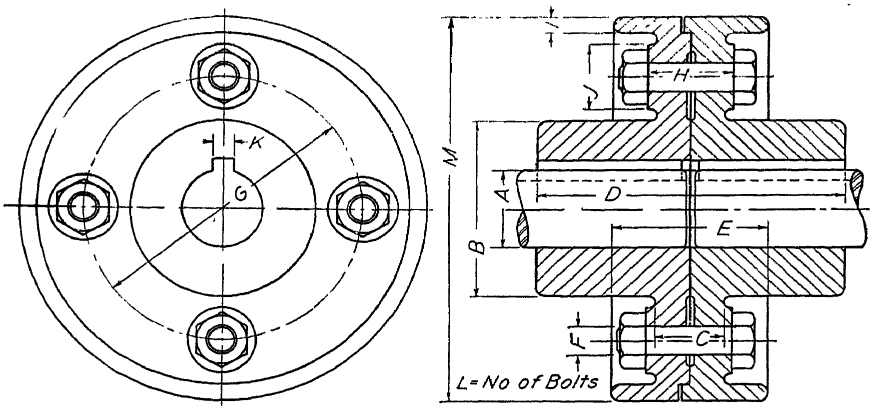


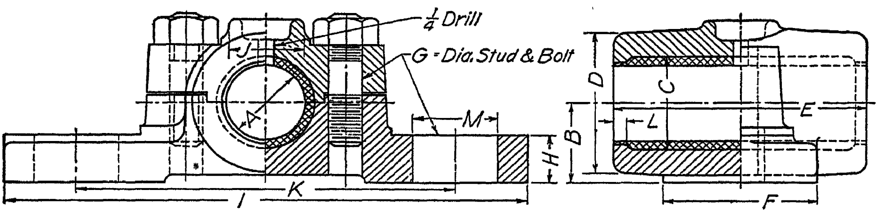
Fig. 611.—Eccentric and strap.



A	B	C	D	E	F	G	H	I	J	K	L	M
1 3/16	2 3/4	1	4 1/2	2 1/4	7/16	4 1/8	1 1/4	1/4	1	5/16	4	6
1 7/16	3 1/2	1	5	2 1/2	1/2	4 13/16	1 1/4	1/4	1 1/16	3/8	4	6 5/8
1 11/16	3 1/4	1 1/8	5 9/16	3	5/8	5	1 3/8	5/16	1 5/16	3/8	5	7 1/4
1 15/16	3 7/8	1 1/4	6 1/8	3 1/4	5/8	5 5/8	1 1/2	5/16	1 5/16	1/2	5	7 3/4
2 3/16	3 7/8	1 3/8	6 5/8	3 1/2	3/4	5 7/8	1 3/4	5/16	1 1/2	1/2	5	8 3/8
2 7/16	4 1/2	1 1/2	7 1/4	3 3/4	3/4	6 3/8	1 7/8	3/8	1 1/2	5/8	5	11

Fig. 612.—Flange coupling.

21, 22. Figs. 612, 613. Make working drawings, assembled. Size to be assigned.



A	B	C	D	E	F	G	H	I	J	K	L	M
1 3/16	1 1/4	1 1/2	2 1/4	3 3/4	2 1/4	1/2	3/4	7 3/4	1 1/8	5 5/8	3/16	1 1/4
1 7/16	1 7/16	1 3/4	2 5/8	4 1/2	2 5/8	1/2	13/16	8	1 1/4	5 7/8	3/16	1 1/4
1 11/16	1 5/8	2 1/16	3	5 1/4	3	1/2	7/8	8 1/2	1 1/4	6 3/8	3/16	1 1/4
1 15/16	1 11/16	2 3/8	3 3/8	6	3 3/8	5/8	7/8	10 1/4	1 3/8	7 11/16	1/4	1 1/2
2 3/16	2	2 11/16	3 3/4	6 3/4	3 3/4	5/8	1	10 3/8	1 1/2	7 7/8	1/4	1 1/2
2 7/16	2 1/8	2 15/16	4 1/8	7 1/2	4	3/4	1 1/16	10 3/4	1 1/2	8 1/4	1/4	1 1/2

Fig. 613.—Pillow block.

Group III. Auxiliary-view Drawings.

23. Fig. 614. Working drawing with right or left auxiliary.
24. Fig. 615. Working drawing with front auxiliary.
25. Fig. 616. Working drawing with right auxiliary.
26. Fig. 617. Working drawing with partial auxiliary.
27. Fig. 618. Working drawing with auxiliary elevation.
28. Fig. 619. Working drawing with partial auxiliary.
29. Fig. 620. Working drawing with front, partial top and partial right and left auxiliaries.

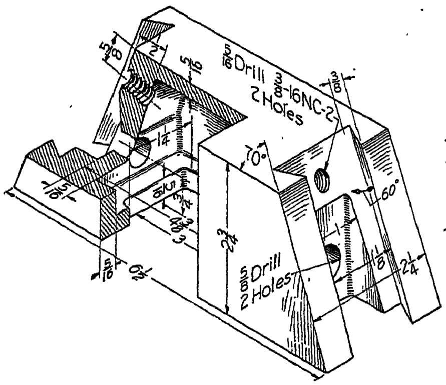


FIG. 614.—Slide base.

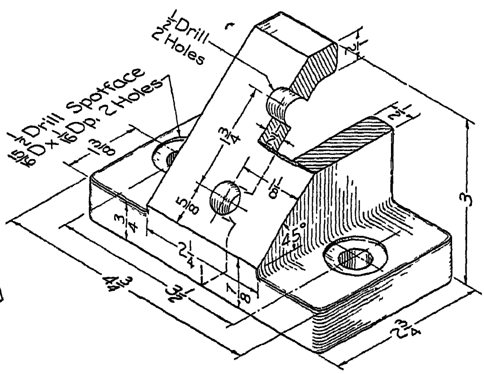


FIG. 615.—Idler bracket.

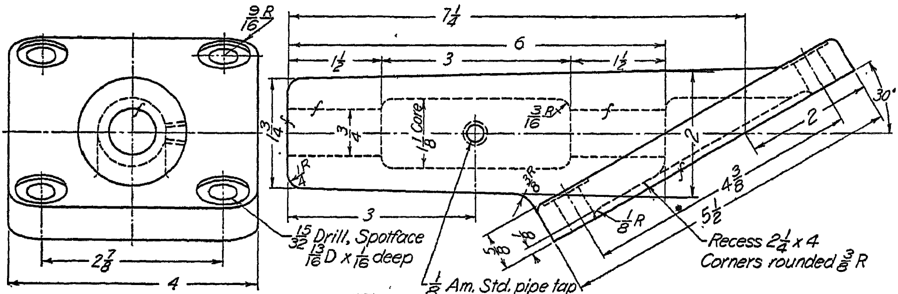


FIG. 616.—Angle bracket.

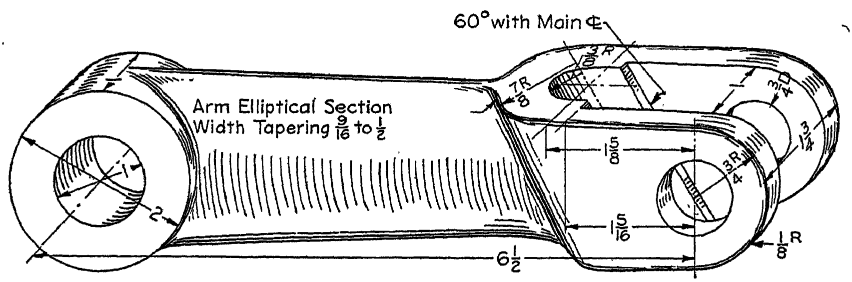


FIG. 617.—Pawl carrier.

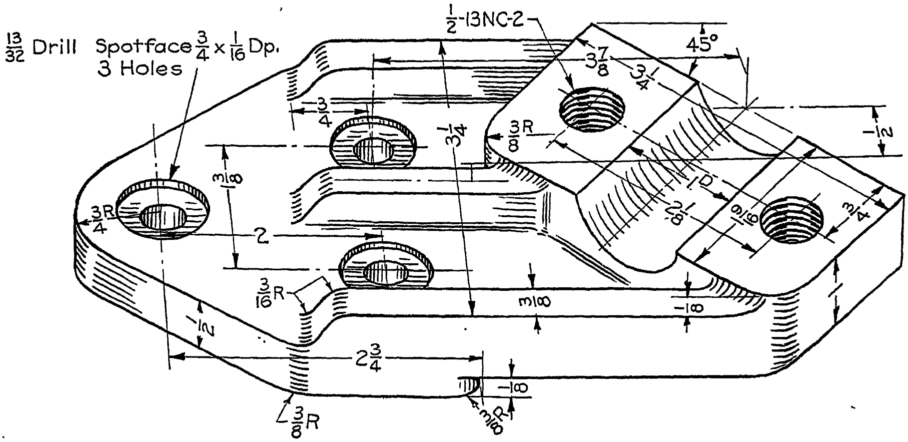


FIG. 618.—Hinge base.

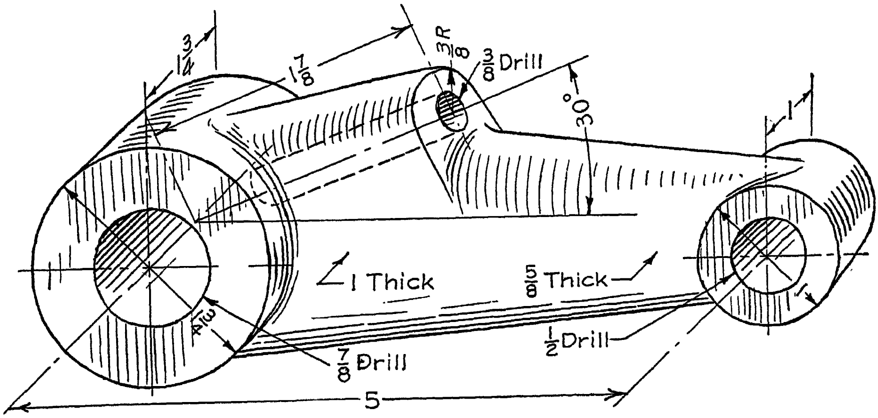


FIG. 619.—Rocker arm.

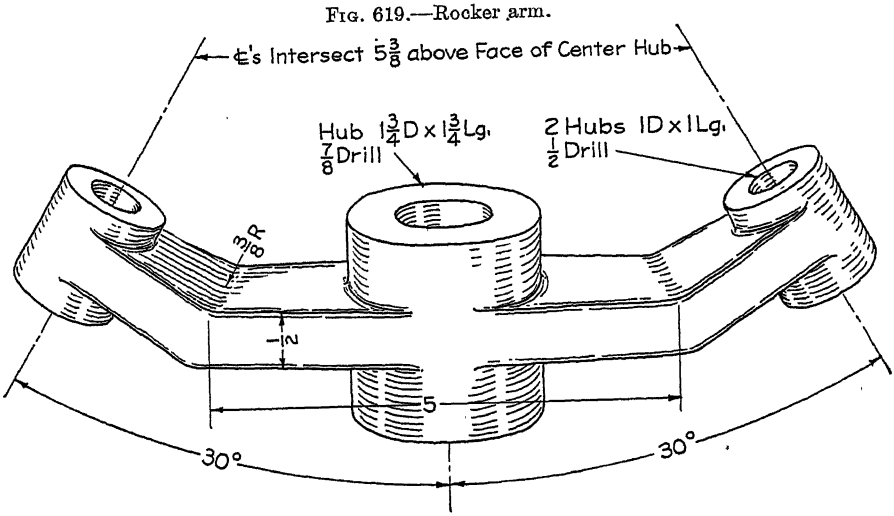


FIG. 620.—Radial swing link.

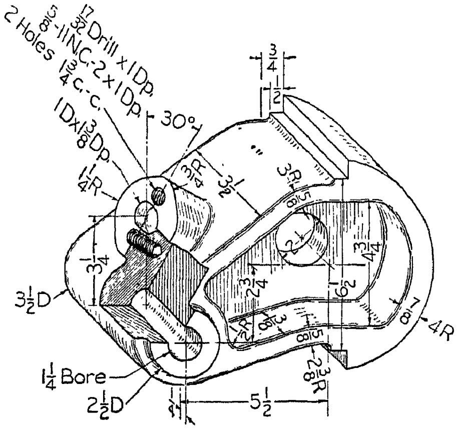


Fig. 621.—Overarm bracket.

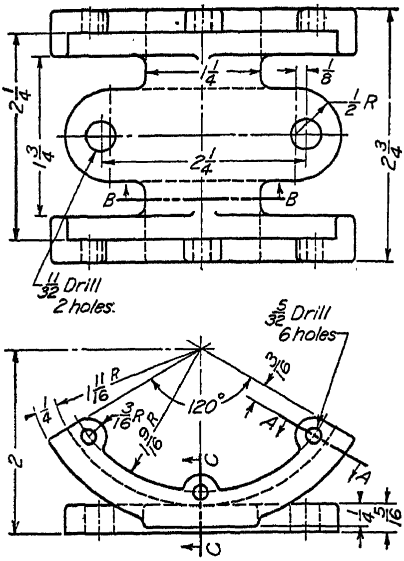


Fig. 622.—Spool base.

30. Fig. 621. Working drawing with partial left auxiliary.
31. Fig. 622. Working drawing with auxiliary sections *A-A*, *B-B* and *C-C*.
32 to **42.** Working drawings with auxiliary views of Figs. 347 to 357.

Group IV. Double Auxiliaries.

43. Fig. 623. Working drawing with double auxiliary.
44, 45, 46, 47. Working drawings of Figs. 358, 360, 361, 363.

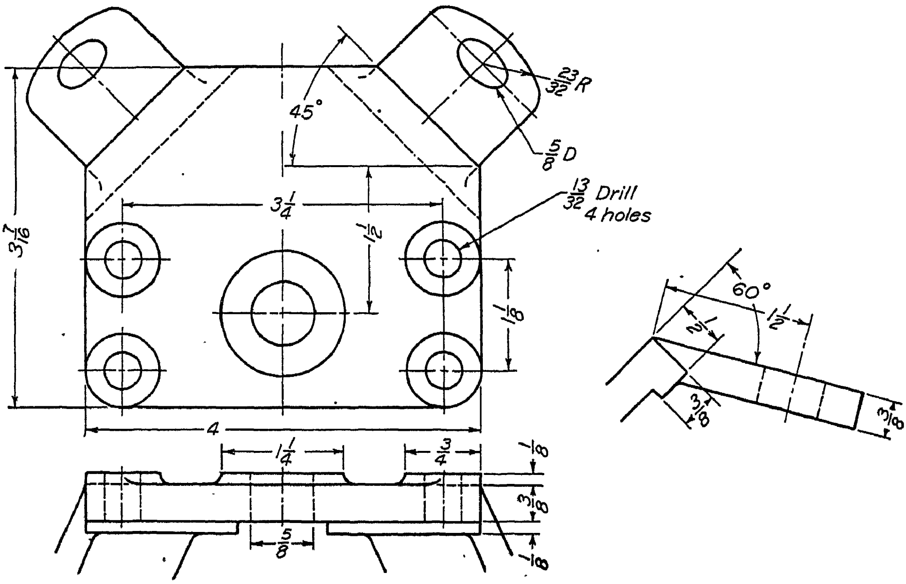


Fig. 623.—Switch-box cover.

Group V. Special Representation.

The group illustrates the statements of paragraphs 140 to 148 concerning the violation of theory in the interest of clearness. Select views carefully and use aligned sections, part views, revolved sections, removed or enlarged sections, etc., to describe the shape. Dimension carefully, giving machining operations where possible.

48. Fig. 624. Working drawing of slotted spider.

49. Fig. 625. Working drawing of valve cage

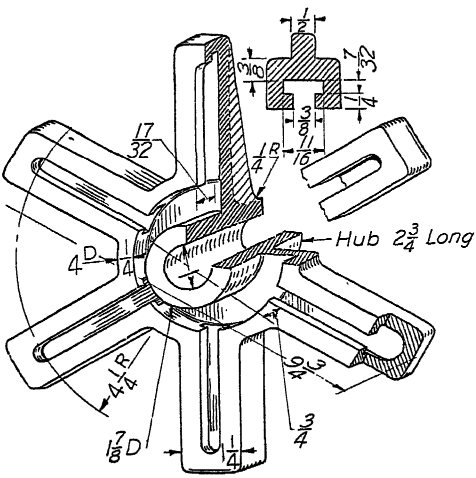


FIG. 624.—Slotted spider.

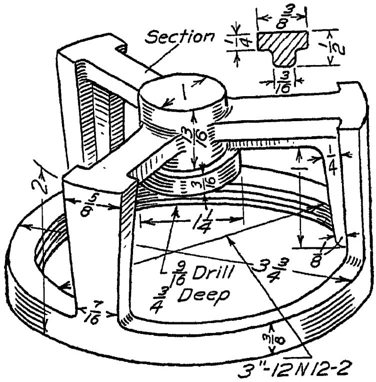


FIG. 625.—Valve cage.

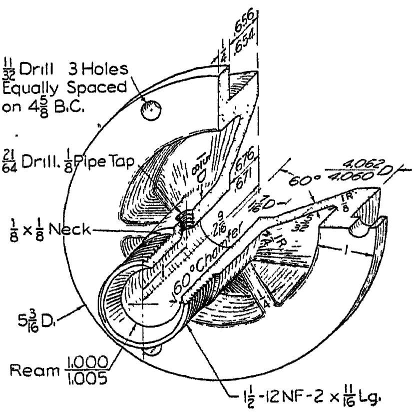


FIG. 626.—Water pump cover.

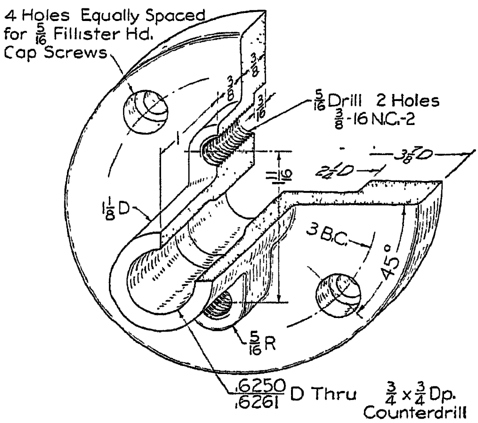


FIG. 627.—Stuffing box seat.

50. Fig. 626. Working drawing of water pump cover.

51. Fig. 627. Working drawing of stuffing box seat.

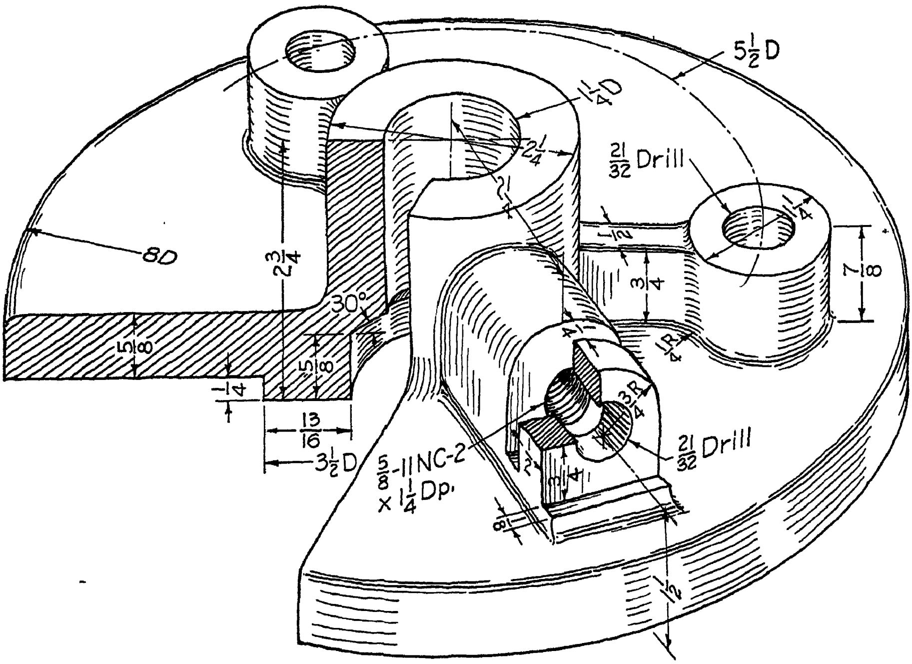


FIG. 628.—Valve flange.

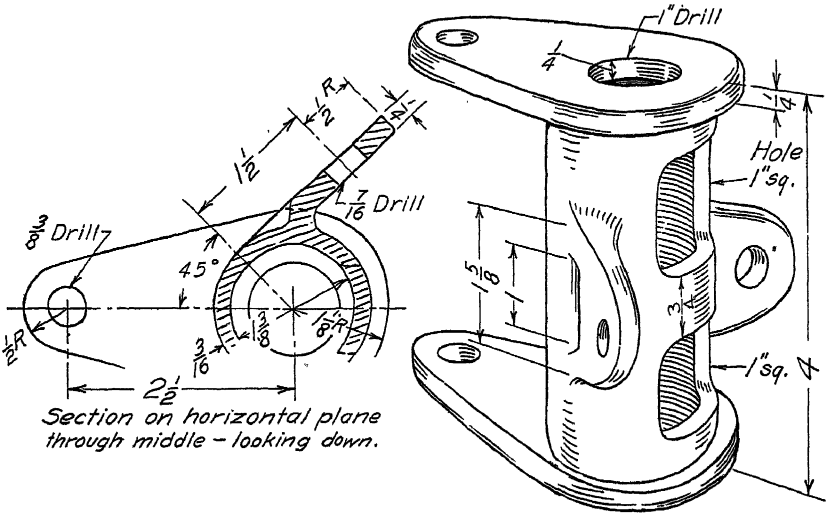


FIG. 629.—Stake socket.

52. Fig. 628. Working drawing of valve flange. The three 1¼" bosses are equispaced. Use top view, partial right side view, and front view as a conventional section.

53. Fig. 629. Working drawing of stake socket. Use top view, partial front view and auxiliary elevation.

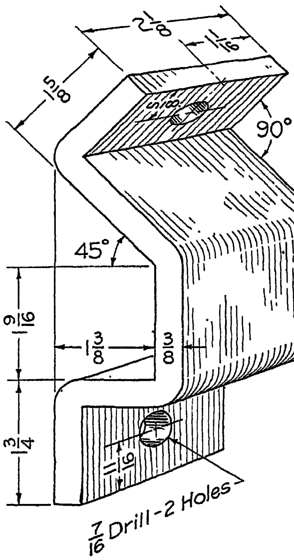


FIG. 630.—Strap.

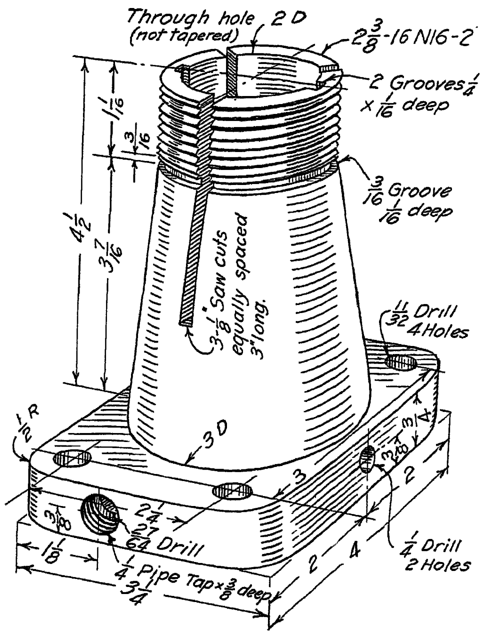


FIG. 631.—Split bushing.

54. Fig. 630. Working drawing with developed view.
55. Fig. 631. Working drawing with conventional section.
56. Fig. 632. Working drawing with aligned view and auxiliary section.

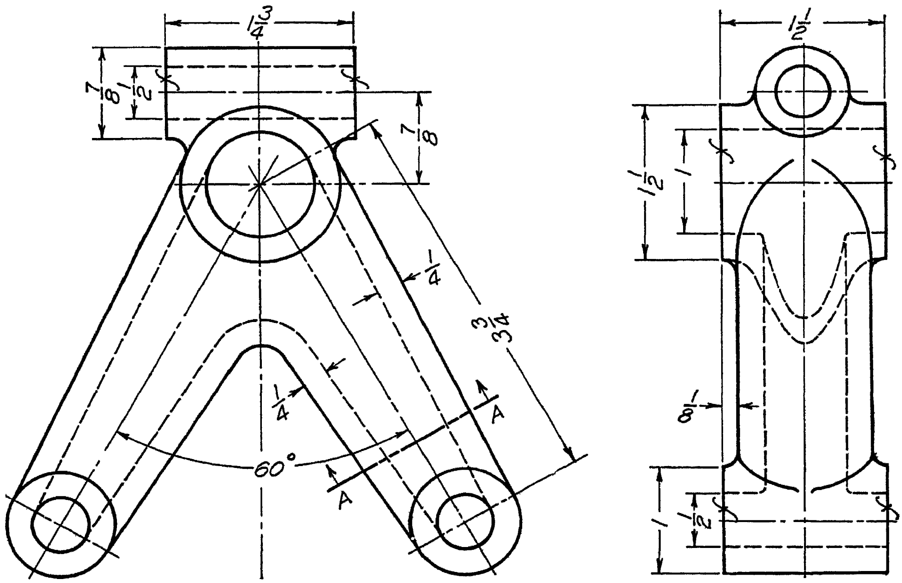


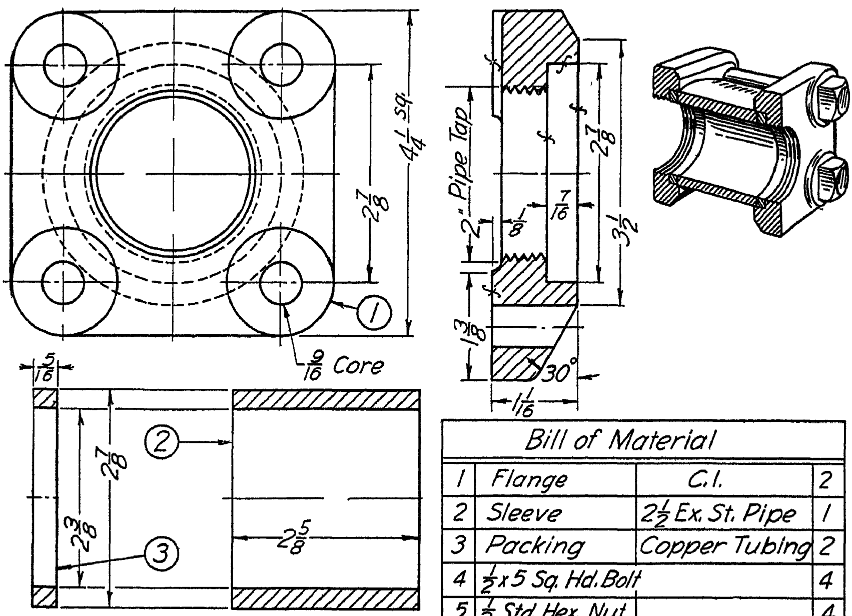
FIG. 632.—Manifold.

Group VI. Small Assembly Drawings from Details.

57. Fig. 633. Make an assembly drawing of the Boyle union, from details given. The pictorial sketch, as well as the identified pieces and bill of material, will assist in identifying the parts for the assembly. The two flanges are screwed on the pipes to be joined, and the sleeve and two packing rings are placed between the flanges. Then bolts are placed and nuts tightened to hold the assembly together and ensure a tight joint. Use two views, end and longitudinal, with longitudinal view in full section. Use conventional symbols for sectioning the different materials. The dimensions of the pipe thread are given in the Appendix.

58. Fig. 634. Make an assembly drawing with bill of material for the pump valve from details given. The valve seat, stem and spring are brass; the disk is hard rubber composition. In operation, pressure of a fluid upward against the disk raises it and allows flow. Pressure downward forces the disk tighter against the seat and prevents flow. Use two views, top and front, with front view in section. See page 154 for conventional representation of ribs in section and page 235 for the conventional method of drawing the spring.

59. Fig. 635. Make an assembly drawing of the ball bearing live center from details given. The "live" type of center is used on machine tools of various types in operations where high speed of the moving part held by the center would cause excessive heating if the stationary or "dead" center were used. The parts may be oriented in the assembly by checking the dimensions of one part against those of another to find mating pieces. The pictorial sketch and the bill of material will also assist. The detail dimensions of the ball bearing may be obtained from the manufacturer's catalogue. Draw both end views, and a longitudinal view in section.



Bill of Material			
1	Flange	C.I.	2
2	Sleeve	2½ Ex. St. Pipe	1
3	Packing	Copper Tubing	2
4	½ x 5 Sq. Hd. Bolt		4
5	½ Std. Hex. Nut		4

Fig. 633.—Boyle union.

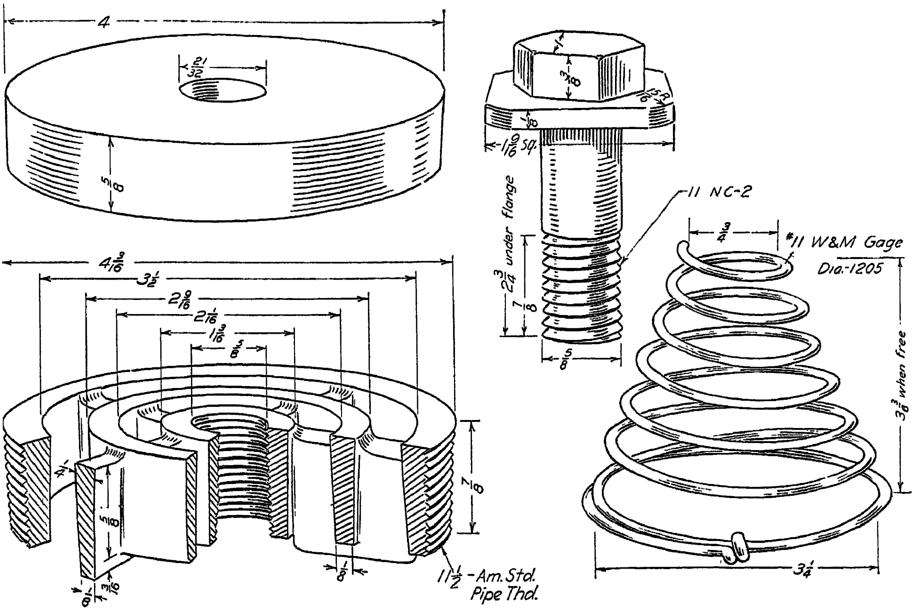
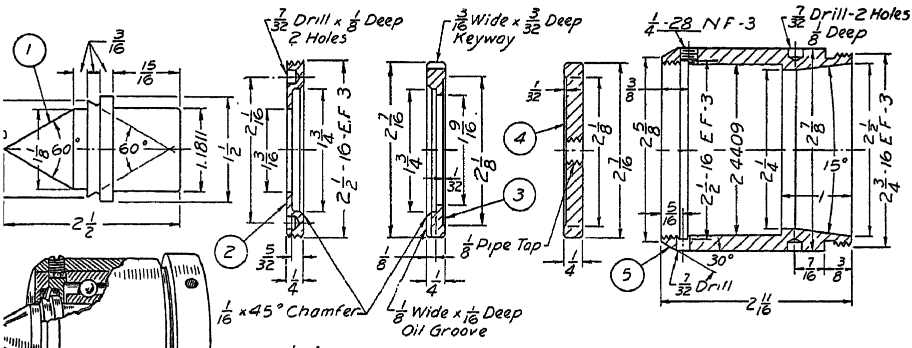
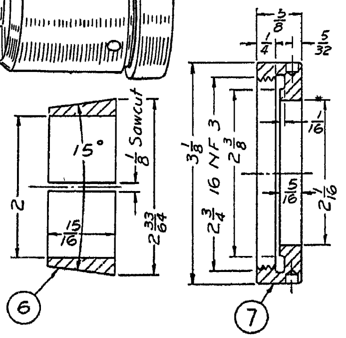


FIG. 634.—Pump valve details.





Bill of Material			
1	Center	Tool Steel	1
2	Front Nut	Mach Steel	1
3	Front Washer	Mach Steel	1
4	Rear Washer	Mach Steel	1
5	Sleeve	C.R. Steel	1
6	Thimble	Mach Steel	1
7	Rear Nut	C.R. Steel	1
8	$\frac{1}{8}$ Pipe Plug	——	1
9	Ball Bearing	#5206-N.D.	1
10	$\frac{1}{4}$ Headless Set Scr.	Dog Point	1

FIG. 635.—Ball-bearing live center.

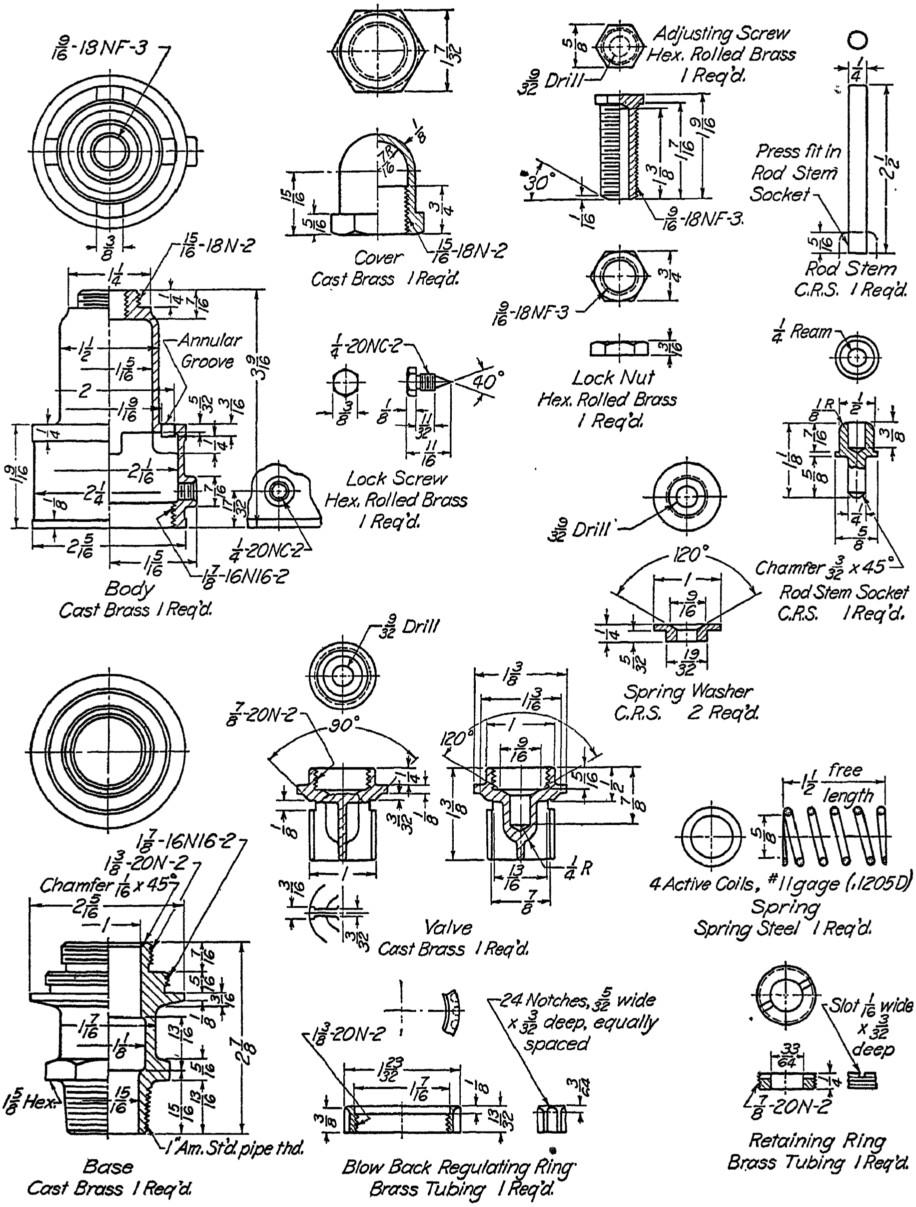


FIG. 636.—Brass relief valve. (*Courtesy of Crane Company.*)

60. Fig. 636. Make an assembly drawing of the brass relief valve from details given. The parts may be oriented in the assembly by checking the dimensions of one part against those of another to find mating pieces. The thread specifications given will also aid materially in locating the parts that are screwed together. Use two views, front and top, with front view in section. Indicate part numbers and make a bill of material.

Group VII. Details from Assembly Drawings.

61. Fig. 637. Make detail drawings of motor support.

62. Fig. 638. Make detail drawings of flexible coupling.

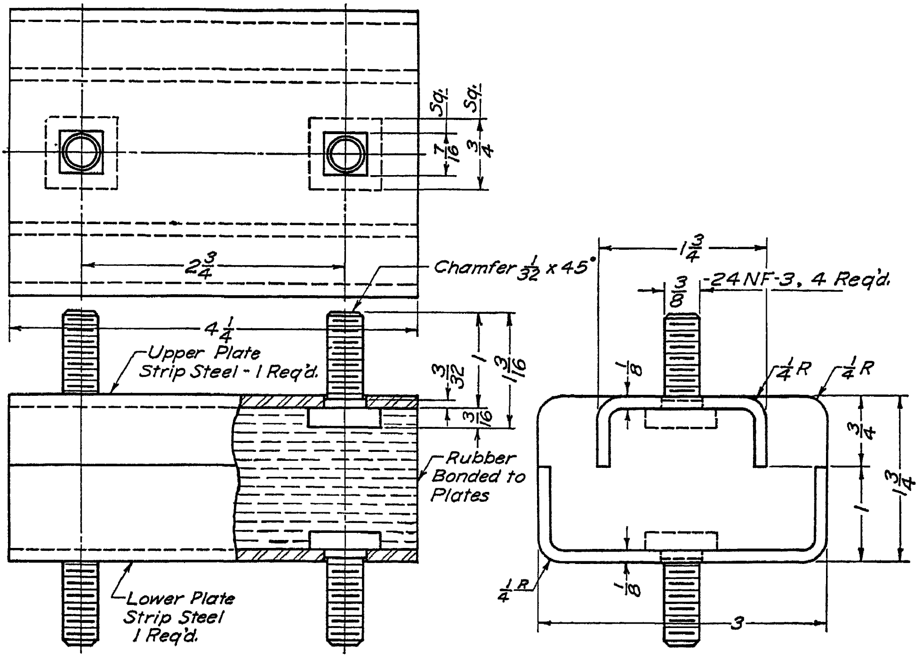
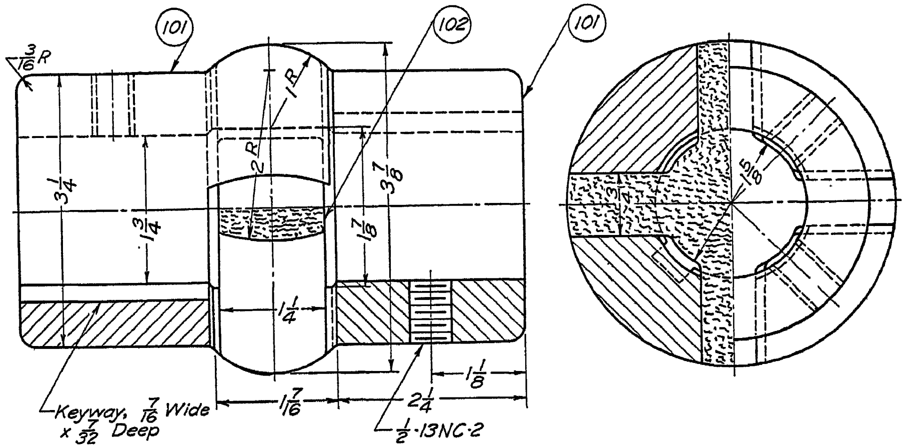


Fig. 637.—Motor support.



PC. NO.	NAME	MAT.	QUAN.	NOTES
101	Clutch	Steel	2	
102	Spider	Rubber	1	Purchased

Fig. 638.—Flexible coupling.

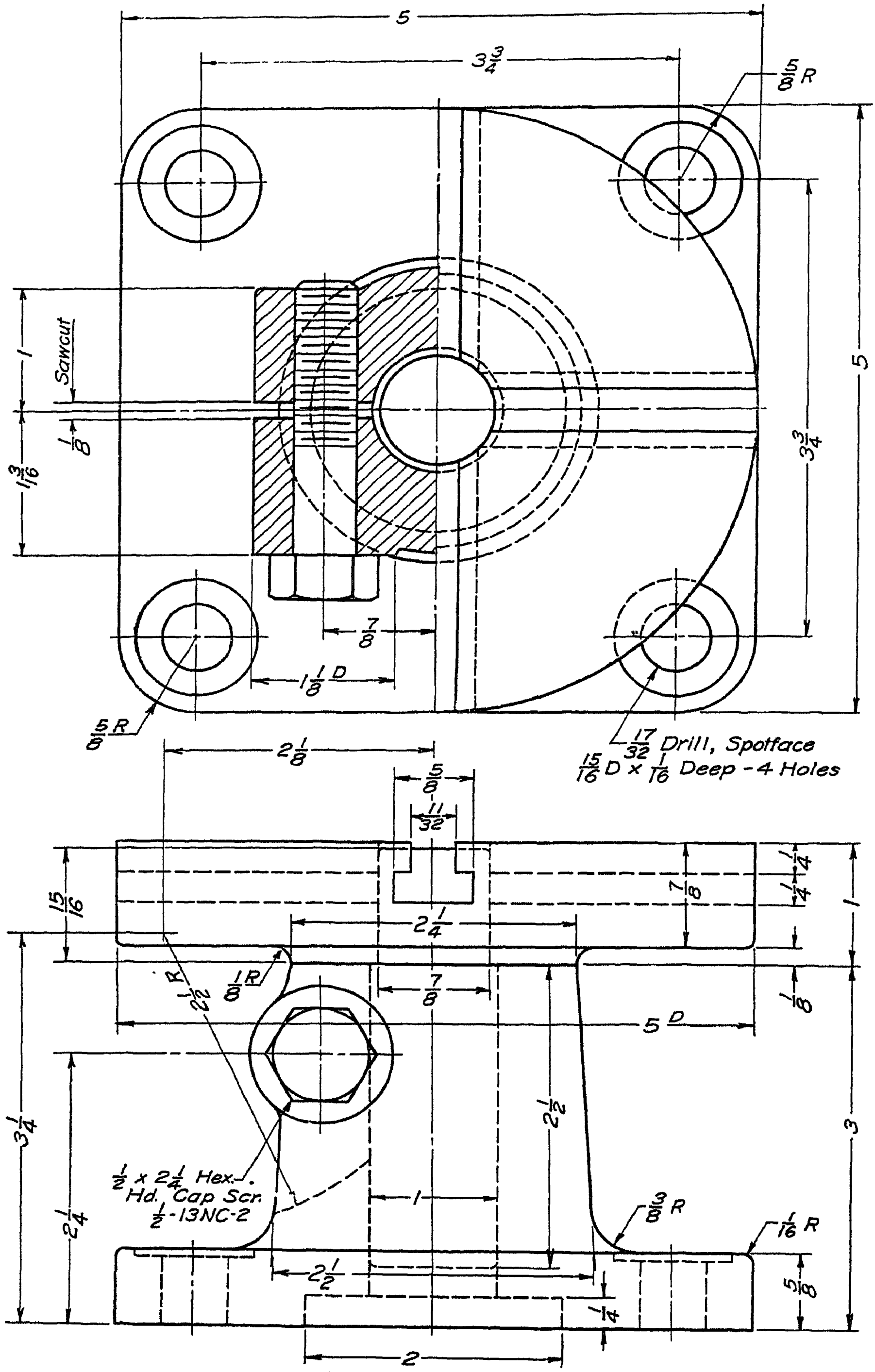
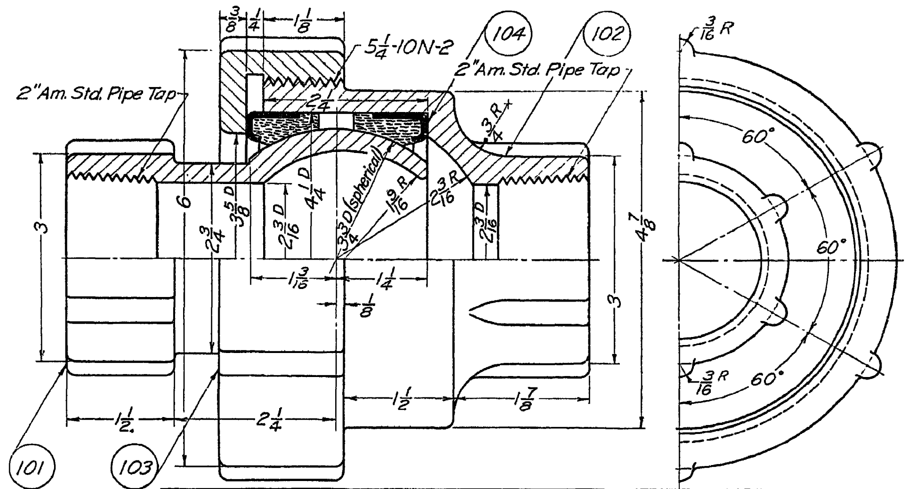


FIG. 639.—Jig table.



PC. NO.	NAME	MAT.	QUAN.	NOTES
101	Ball Fitting	Mal. I.	1	
102	Threaded Fitting	Mal. I.	1	
103	Gland	Mal. I.	1	
104	Packing	—	2	Purchased

FIG. 640.—Screw-end ball joint.

63. Fig. 639. Make detail drawings of jig table.
64. Fig. 640. Make detail drawings of ball joint.
65. Fig. 641. Make detail drawings of compensating nut. The purpose of this device is to take up the wear resulting from heavy duty imposed on a feed screw. To adjust the nut the cap screw at the left is loosened and the nut on the draw screw is tightened, the wedging action pushing the loose nut to the left until all lost motion is taken up.

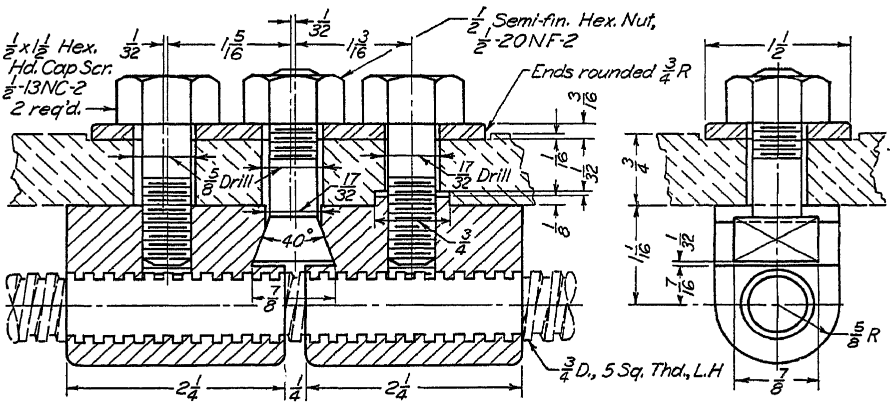


FIG. 641.—Compensating nut.

66. Fig. 642. Make detail drawings of belt drive.
67. Fig. 643. Make detail drawings of valve and seat.

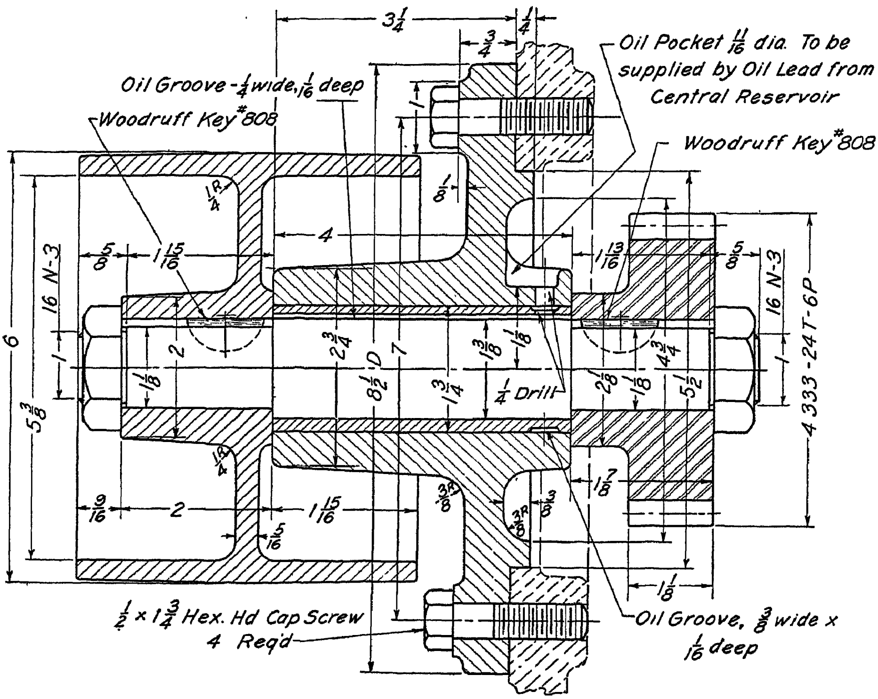
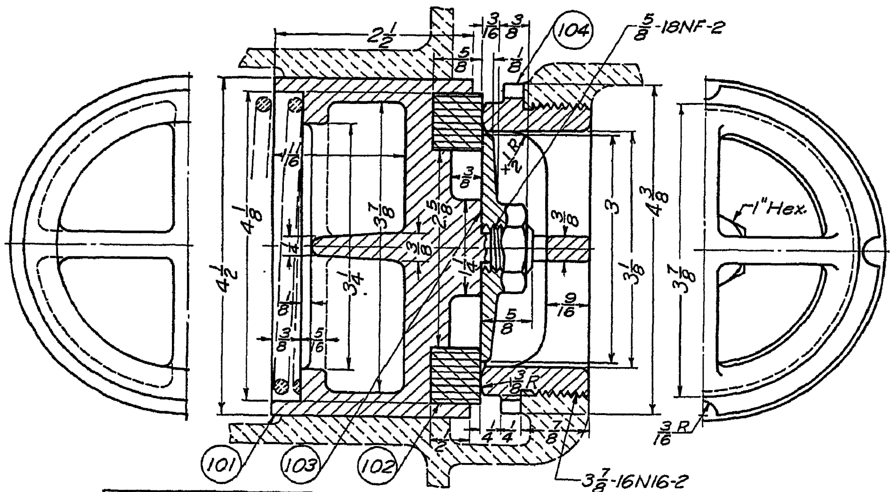
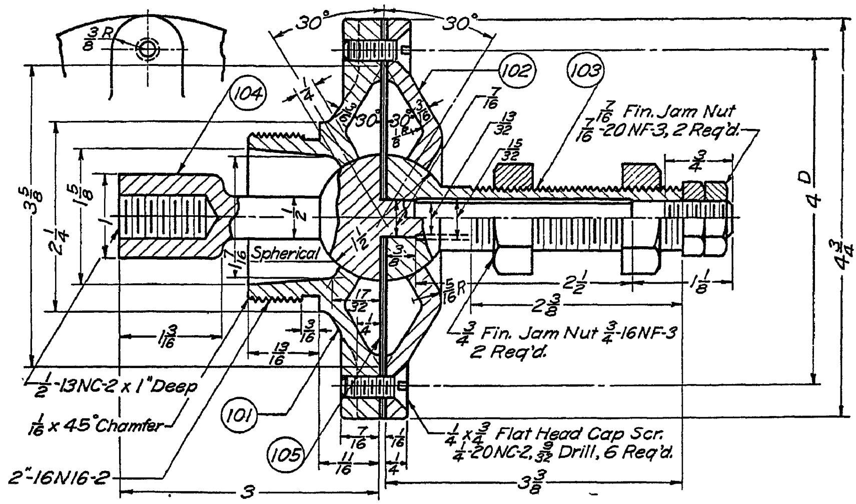


FIG. 642.—Belt drive.



PC. NO.	NAME	MAT.	QUAN.	NOTES
101	Valve	Bro.	1	
102	Valve Ring	Comp.	1	Purchased
103	Valve Nut	Bro.	1	
104	Valve Seat	Bro.	1	

FIG. 643.—Valve and seat



PC. NO.	NAME	MAT.	QUAN.	NOTES
101	Base	Mal. I.	1	
102	Cover	Mal. I.	1	
103	Sleeve Ball	Steel	1	
104	Stud Ball	Steel	1	
105	Diaphragm	Fabric	1	Purchased

FIG. 644.—Sealed ball joint.

68. Fig. 644. Make detail drawings of sealed ball joint.
69. Fig. 645. Make detail drawings of belt tightener.

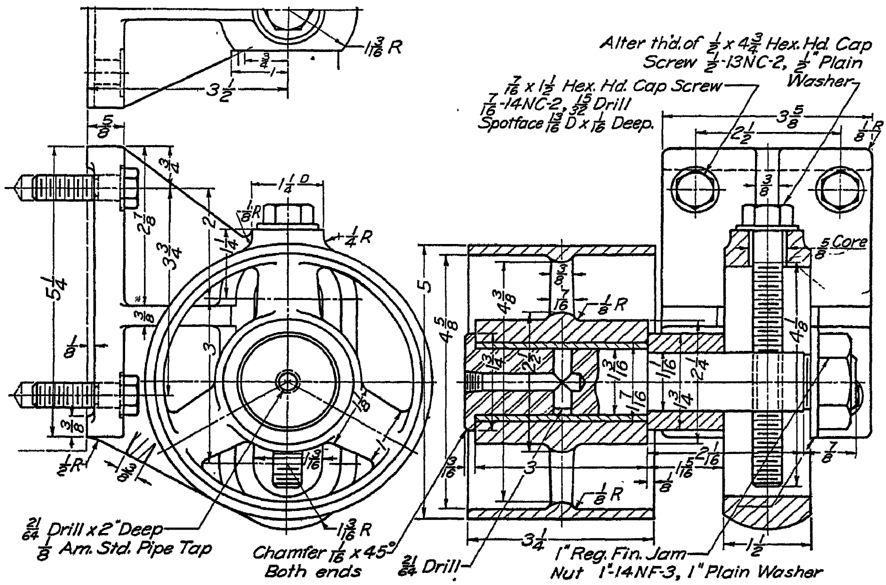


FIG. 645.—Belt tightener.

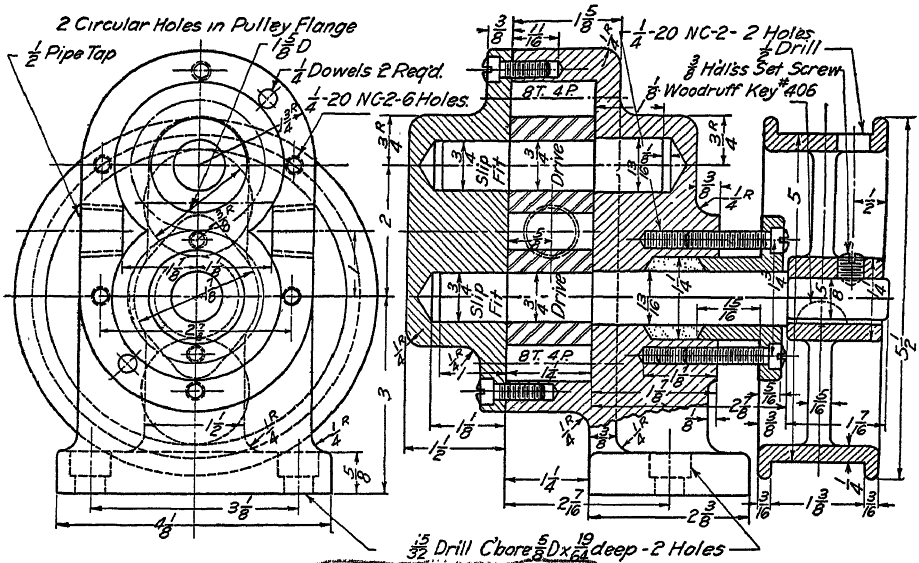


FIG. 646.—Lubricant pump.

70. Fig. 646. Make detail drawings of lubricant pump. Note that on the end view, shown with cover removed, the gears are represented conventionally.

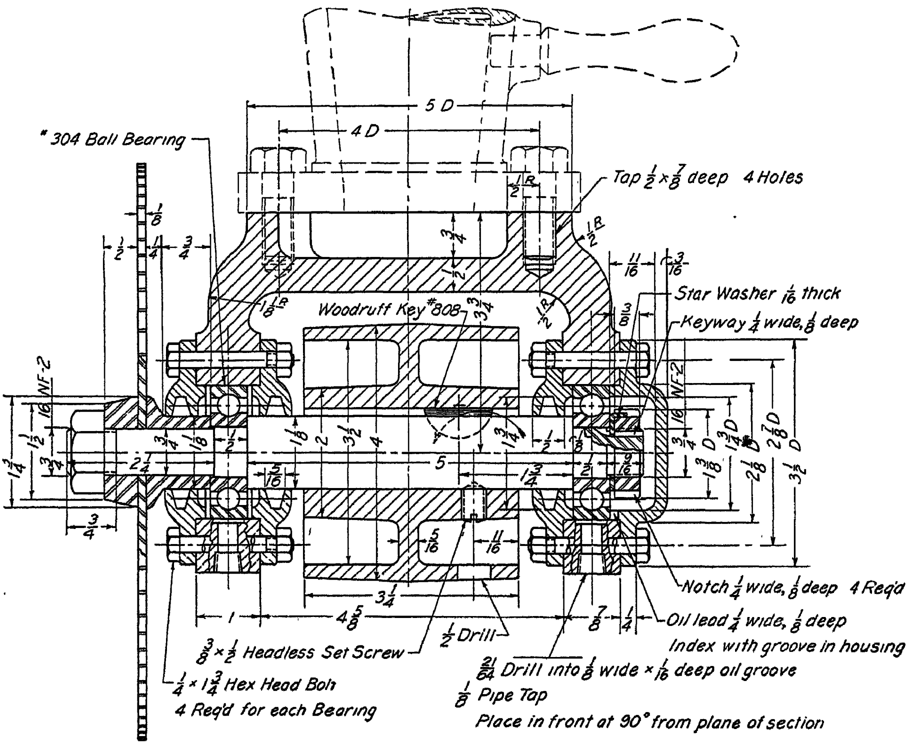


FIG. 647.—Swing-saw frame head.

71. Fig. 647. Make detail drawings and bill of material for swing-saw frame head. The bearing sizes may be obtained from a ball-bearing catalogue. For belt clearance make base elliptical, 5″ × 4″

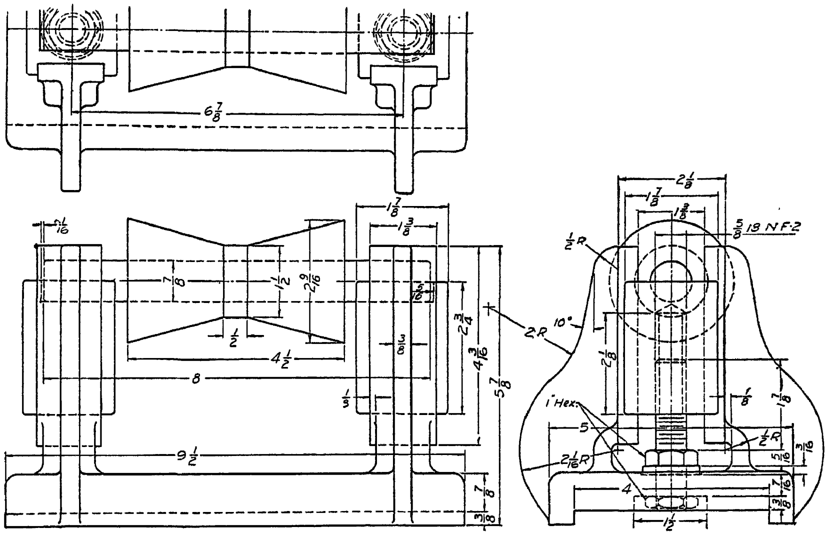
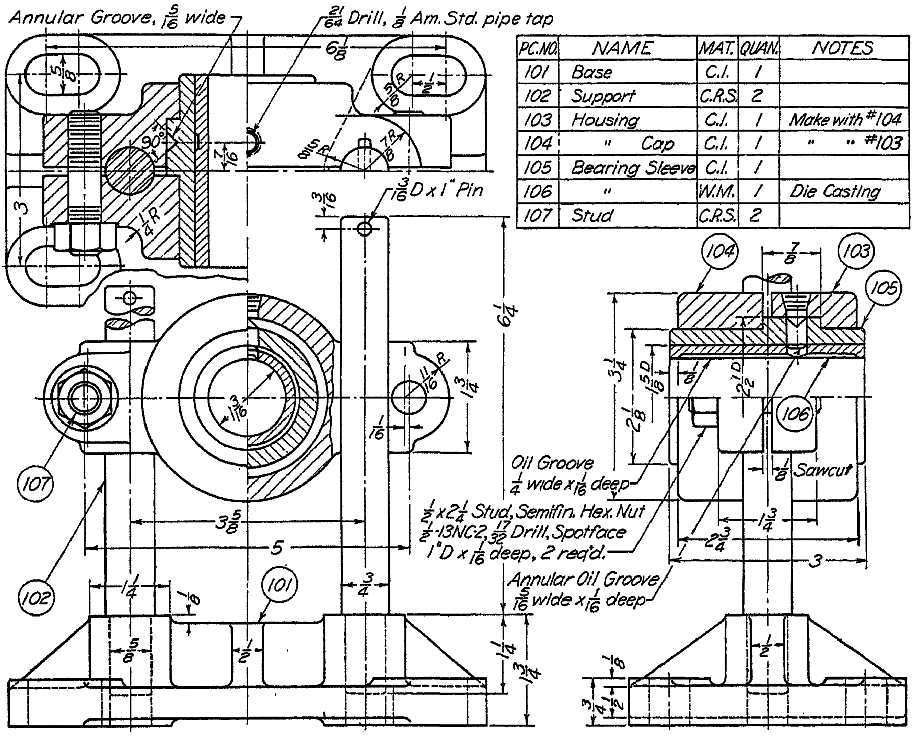


FIG. 648.—Adjustable roller stand (see page 291).



PC. NO.	NAME	MAT.	QUAN.	NOTES
101	Base	C.I.	1	
102	Support	C.R.S.	2	
103	Housing	C.I.	1	Make with #104
104	" Cap	C.I.	1	" " #103
105	Bearing Sleeve	C.I.	1	
106	"	W.M.	1	Die Casting
107	Stud	C.R.S.	2	

FIG. 649.—Adjustable mid-bearing (see page 291).

PC. NO.	NAME	MAT.	QUAN.	NOTES
101	Plate	C.I.	1	St'd. Paint
102	Cam	C.S.	1	
103	Half Nut	C.I.	1	
104	Lever	C.I.	1	St'd. Paint
105	Handle	C.R.S.	1	
106	Pin	C.R.S.	2	

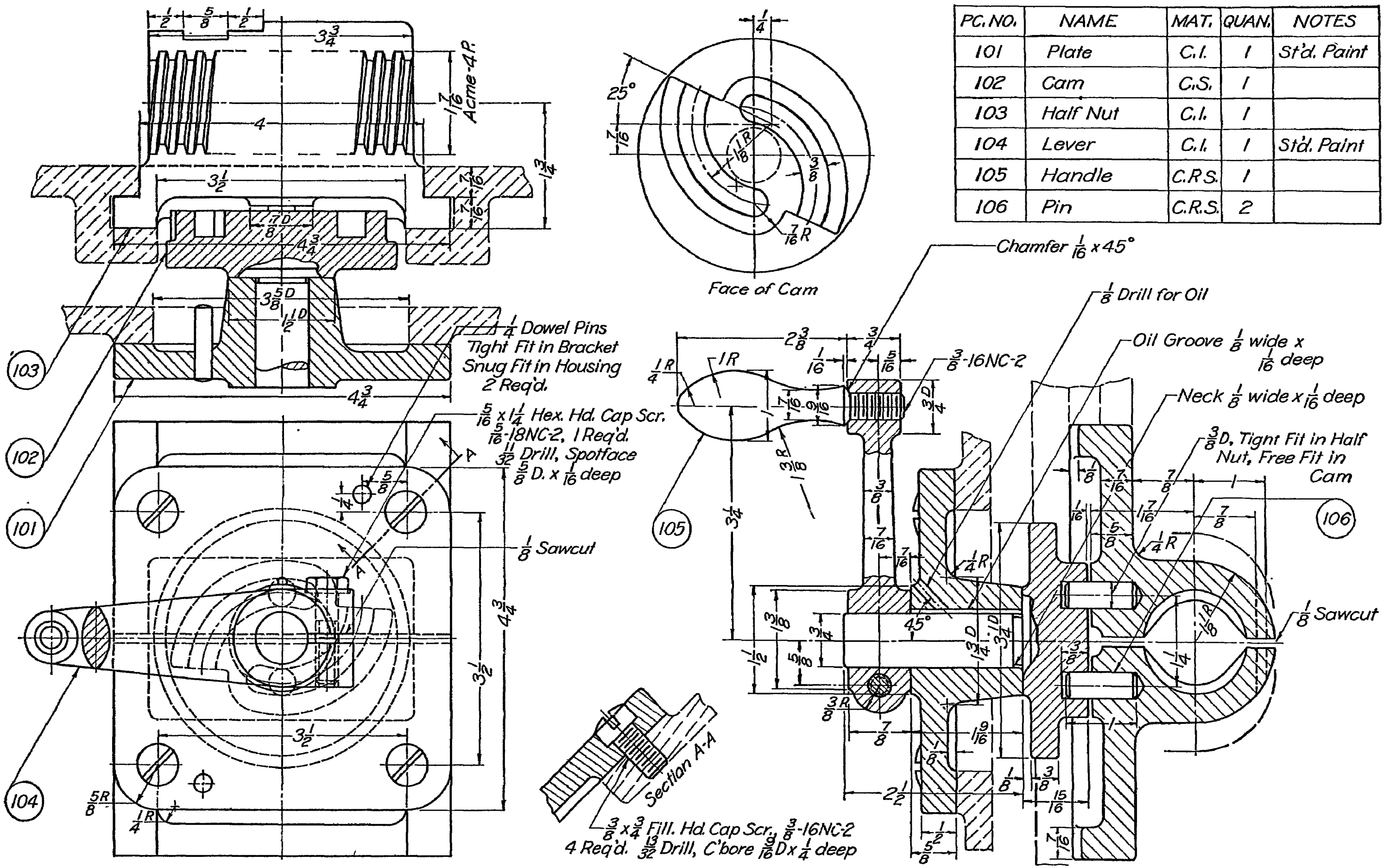


FIG. 650.—Split nut (see page 291).

PC.NO.	NAME	MAT.	NOTES
1	Base	C.I.	
2	Jaw	Steel	Harden
3	Screw	C.R.S	
4	Collar	"	
5	#4 Taper Pin	Steel	Purchase

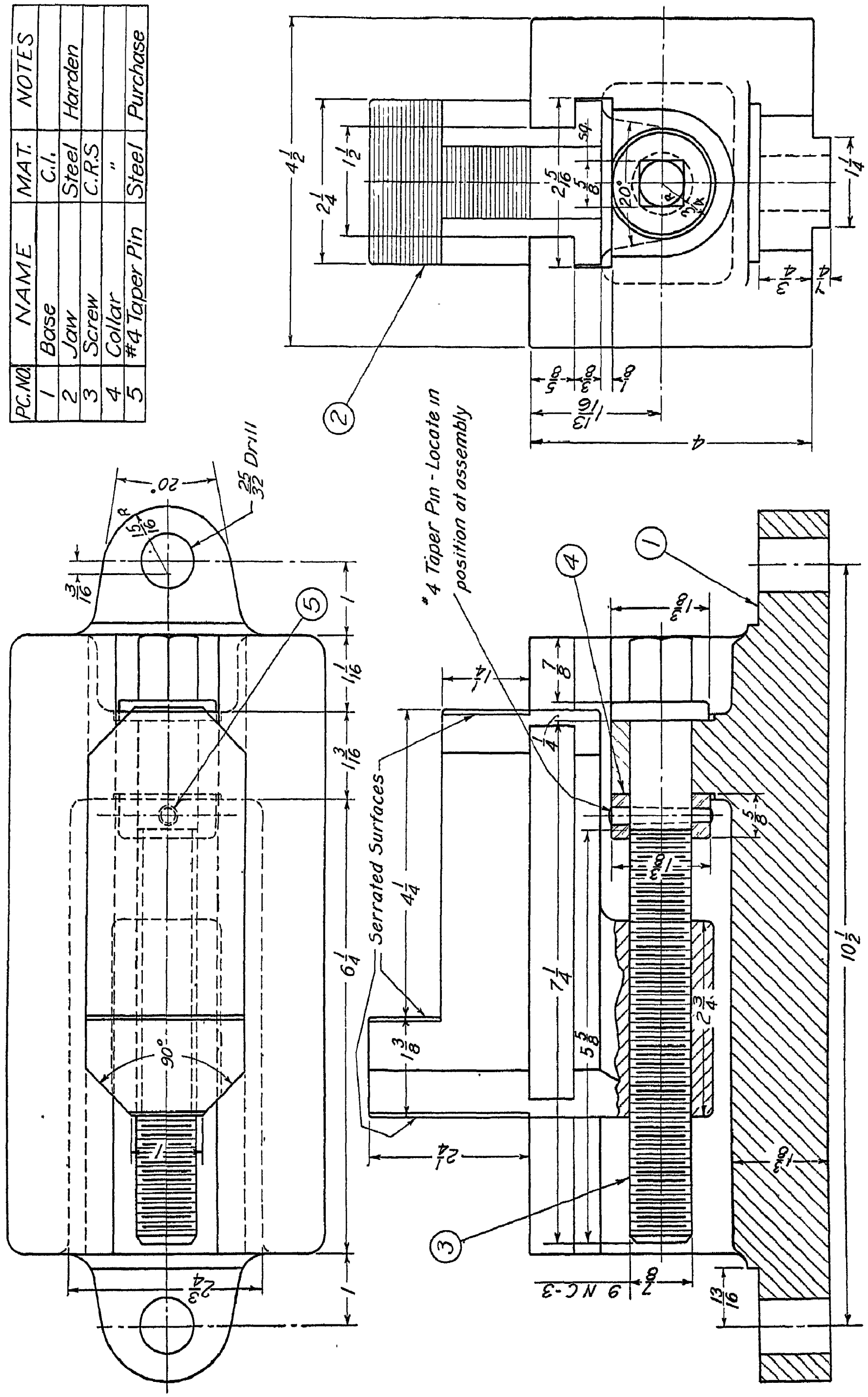


FIG. 651.—Independent faceplate chuck (see page 291).

PC. NO.	NAME	MAT.	QUAN.	NOTES
101	Bracket	C.I.	1	
102	Pulley	C.I.	1	
103	Flange	C.I.	2	
104	Shaft	Steel	1	
105	Sleeve	Steel	1	
106	Nut	Steel	1	

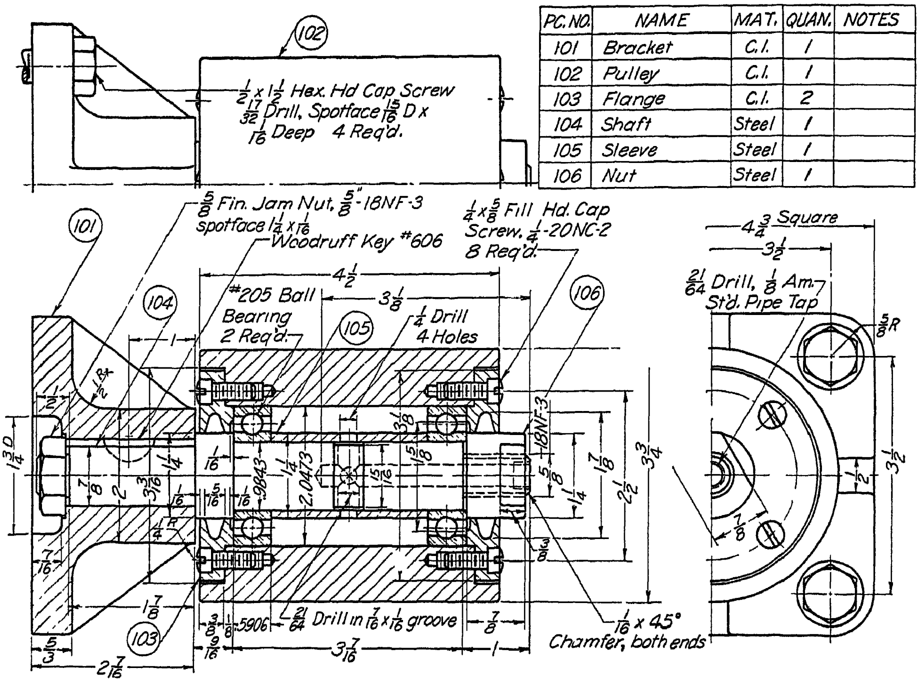


FIG. 652.—Ball-bearing idler pulley.

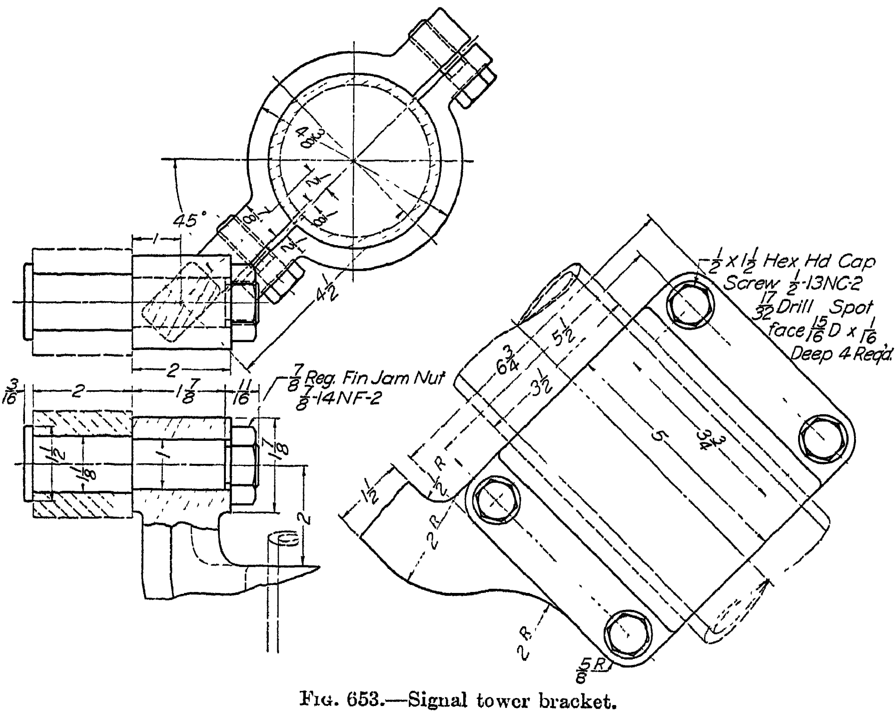


FIG. 653.—Signal tower bracket.

PC.NO.	NAME	MAT.	QUAN.	NOTES
101	Housing	C.I.	1	
102	Sleeve	C.I.	1	
103	Dome	C I	1	
104	Plate	Steel	1	
105	Stud	Steel	4	
106	Filter Unit	—	1	Purchased
107	Gasket	Fiber	1	Purchased

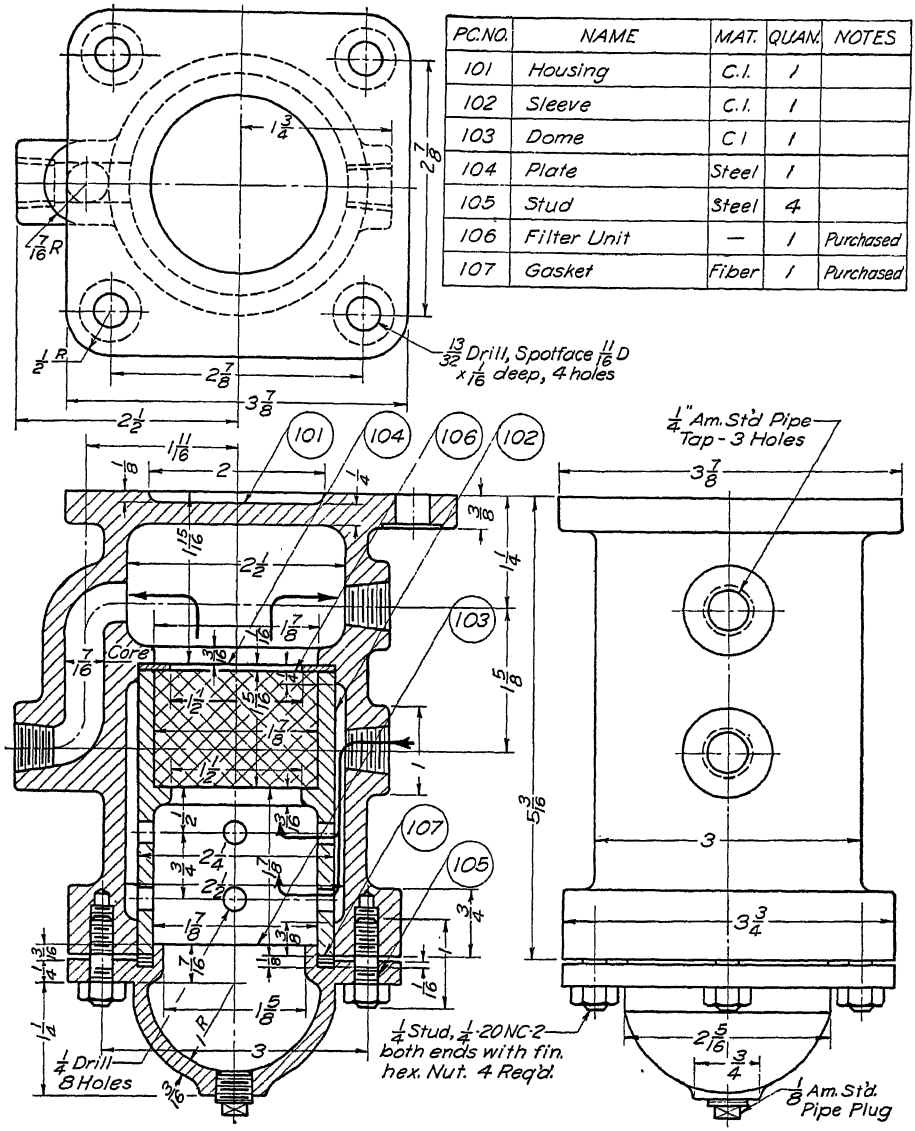


FIG. 654.—Air filter.

72. Fig. 648. Make detail drawings of adjustable roller stand.

73. Fig. 649. Make detail drawings of adjustable mid-bearing.

74. Fig. 650. Make detail drawings for split nut. This well-known mechanism provides for engagement and disengagement of a nut on a screw while the screw is in motion. A 90° movement of the hand lever actuates the two pins in the half nuts by means of the milled slots in the cam, thus raising or lowering the half nuts.

75. Fig. 651. Make detail drawing of independent faceplate chuck.

76. Fig. 652. Make detail drawings of ball-bearing idler pulley.

77. Fig. 653. Make detail drawings of signal-tower bracket.

78. Fig. 654. Make detail drawings of air filter.

Group VIII. Checking Studies.

The drawings in this group are incorrect in technique, representation and dimensioning. Check for errors, following the system given in paragraph 263, and redraw in good form, redesigning to better proportions where advisable. Mark the faults in pencil on the figure before redrawing.

Where the dimensions of a number of details do not add to the over-all dimension given, change one or more dimensions in order to correct the error. Be careful to check for missing lines and errors in projection before redrawing. Note carefully the choice of views, and in redrawing, use views that will best describe the shape.

79. Fig. 655. Check for errors and redraw bar slide.

80. Fig. 656. Redraw rocker arm, correcting all mistakes.

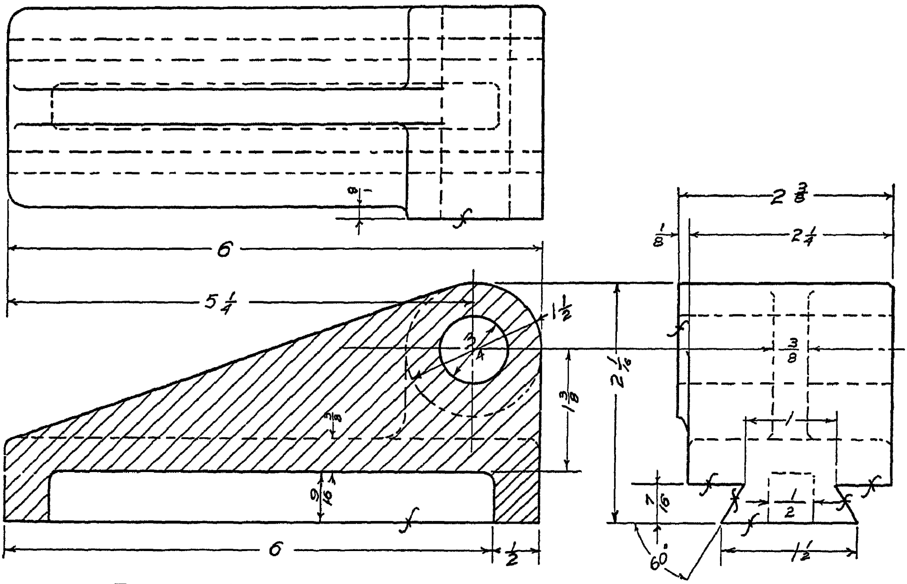


FIG. 655.—An **incorrect** drawing to be checked for errors (bar slide).

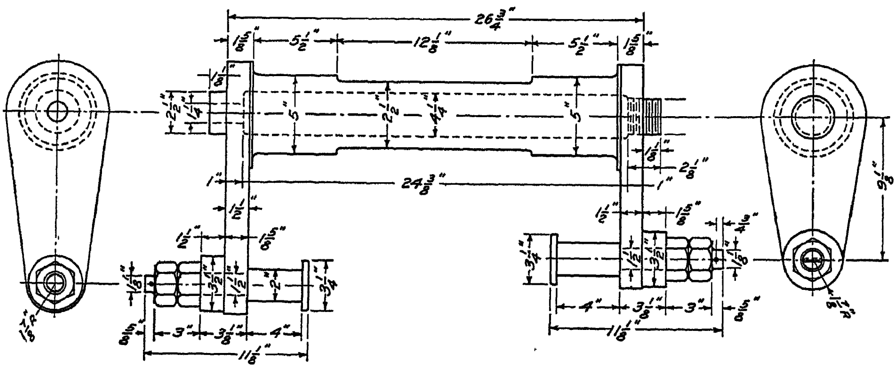


FIG. 656.—An **incorrect** drawing to be checked for errors (rocker arm).

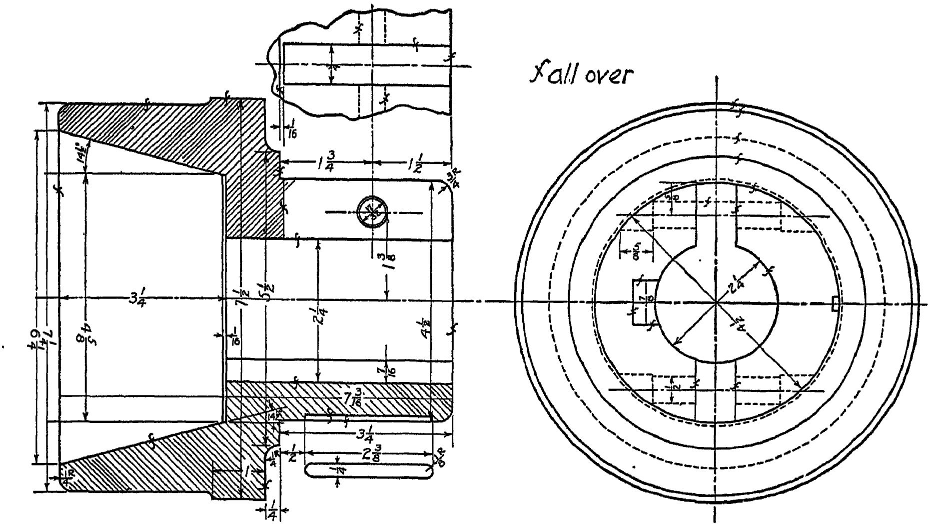


FIG. 657.—An incorrect drawing to be checked for errors (driven cone).

81. Fig. 657. Check errors and redraw driven cone.

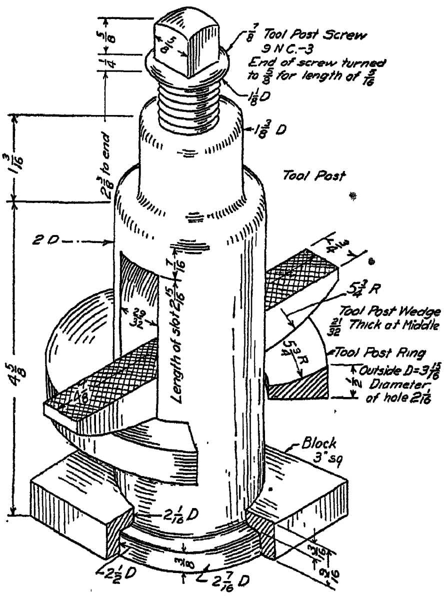


FIG. 658.—Tool post.

Group IX. Assembly and Detail Drawings.

82. Fig. 658. Make assembly and detail drawings for tool post. For assembly, use three views, top, front and side, with front view in section. The material for all parts is steel.

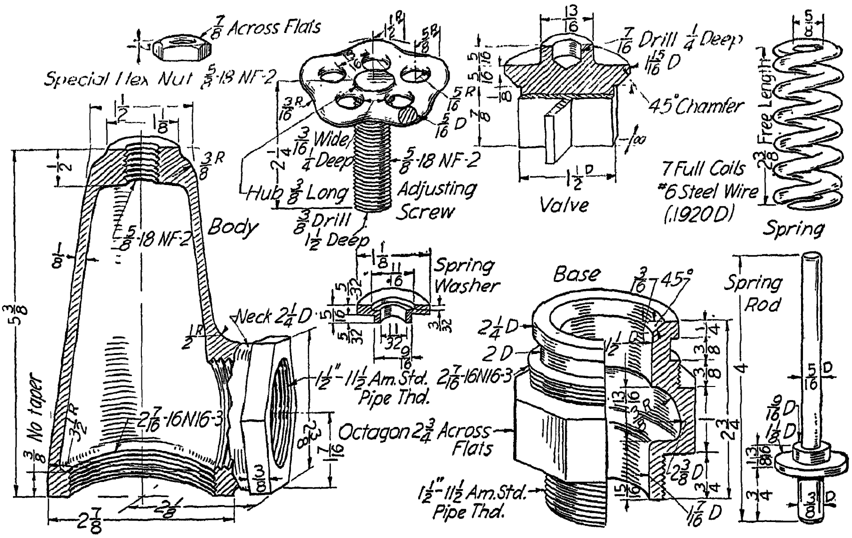


FIG. 659.—Detail sketches of pop-off valve.

83. Fig. 659. Make assembly and details of pop-off valve. All brass except the spring. Use two views, top and front, with front view in section, for assembly drawing. Indicate part numbers and make a bill of material.

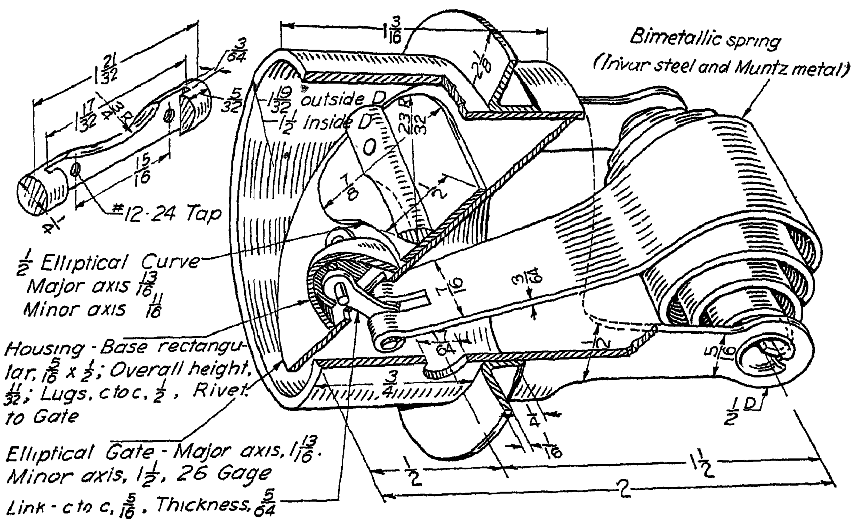


FIG. 660.—Automotive thermostat.

84. Fig. 660. Make assembly and details of automotive thermostat to double size. In detailing the bimetallic spring, use a development to show the shape before coiling. The width changes uniformly from 1½″ at the base to 7⁄16″ at the end.

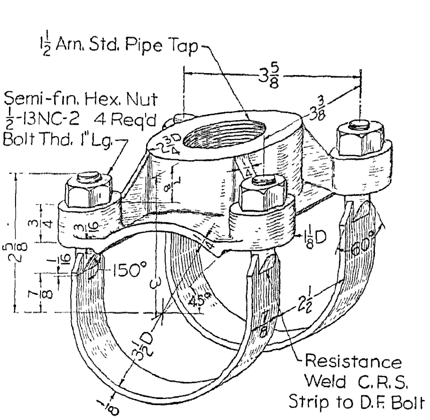


FIG. 661.—Pipe clamp.

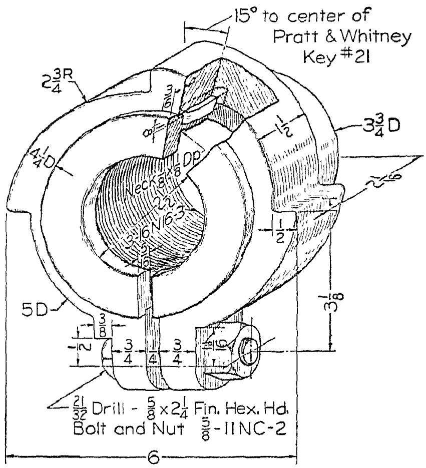


FIG. 662.—Drill-head clamp.

85. Fig. 661. Make assembly and detail drawings of pipe clamp. Detail the strap and bolt together and use resistance-welding symbol to specify the weld required. See Chap. XV for resistance-welding symbols and the specification of resistance welds.

86. Fig. 662. Make assembly and detail drawings of drill-head clamp. The assembly consists of two pieces, split nut and clamp, with Pratt and Whitney key and bolt as purchased parts. The dimensions of Pratt and Whitney keys are given in the Appendix.

87. Fig. 663. Make assembly drawing and bill of material for expansion joint. Indicate piece numbers on the assembly drawing. Show maximum movement of sliding sleeve (piece 3) with alternate position lines.

88. Fig. 664. Make assembly drawing of drill-press vise. Show maximum opening of jaws with alternate position lines.

89. Fig. 665. Make assembly drawing of bench grinder. Use three views, top, front and side, and make the assembly in outline form as indicated in the sketch given. Show one bearing cap removed, in order to show type of bearing surface.

90. Fig. 666. Make assembly drawing of telescopic screw jack, with front view in section. Make a bill of material on a separate sheet. Show jack partially opened and give dimensions from base to top of cap for lowest and highest positions. Handle and handle shaft may be shown broken in order to save space and reduce th sheet size. Refer to Chap. XVI for the method of drawing the teeth of the bevel gears.

91. Fig. 667. From detail sketches, make assembly and detail drawings of *Unipump* centrifugal pump, as made by the Weinman Pump Company, in which the pump casing is mounted directly on a driving motor, making a compact and efficient design. Cross sections of the volute taken at intervals of 45° should be shown by removed sections, either successive or superimposed, and similar sections should be made through the impeller. At 3,425 rpm this pump delivers 520 gallons per minute against a head of 160 feet.

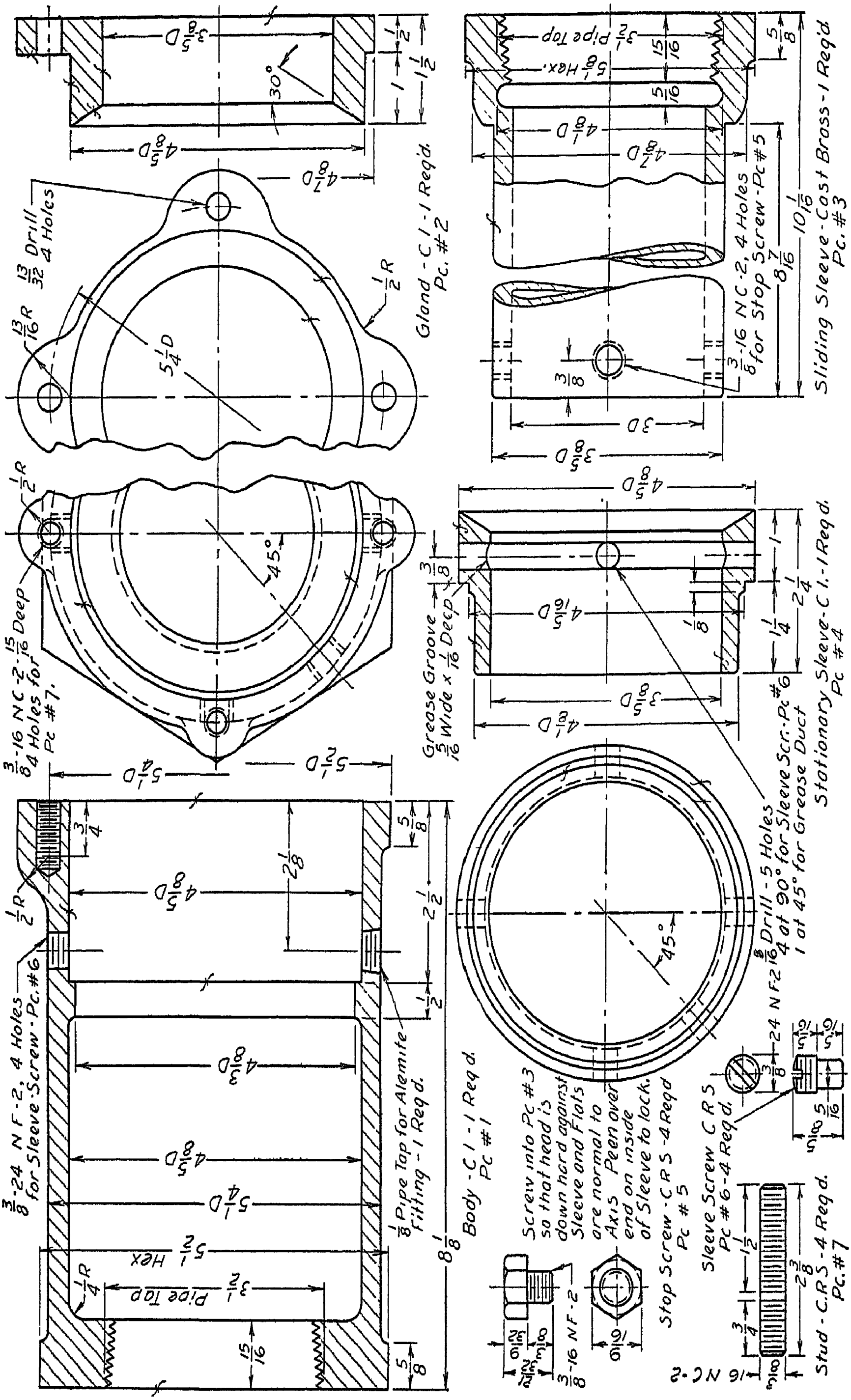


FIG. 663.—Expansion joint (see page 295).

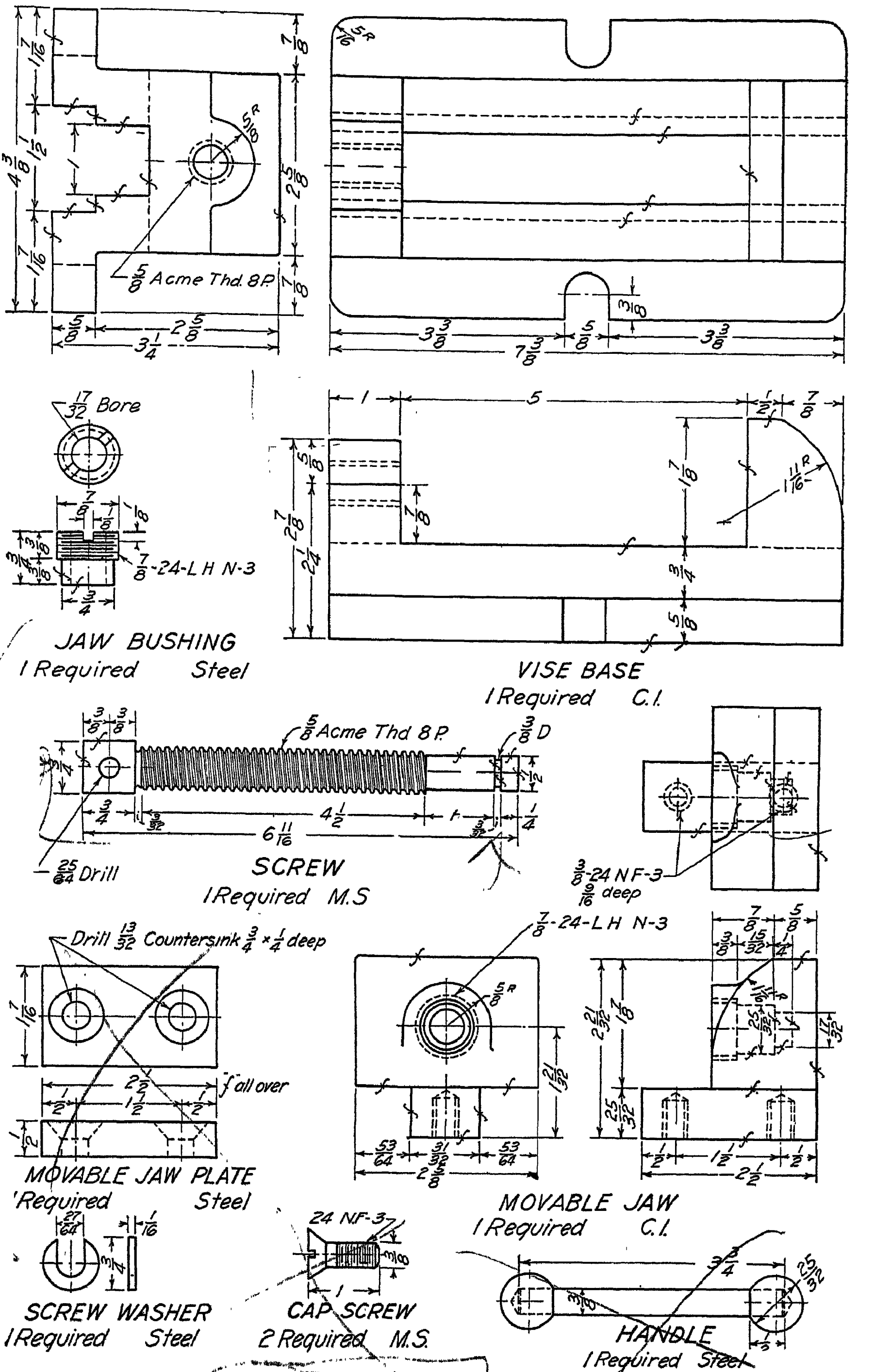


FIG. 664.—Drill-press vise (see page 295).

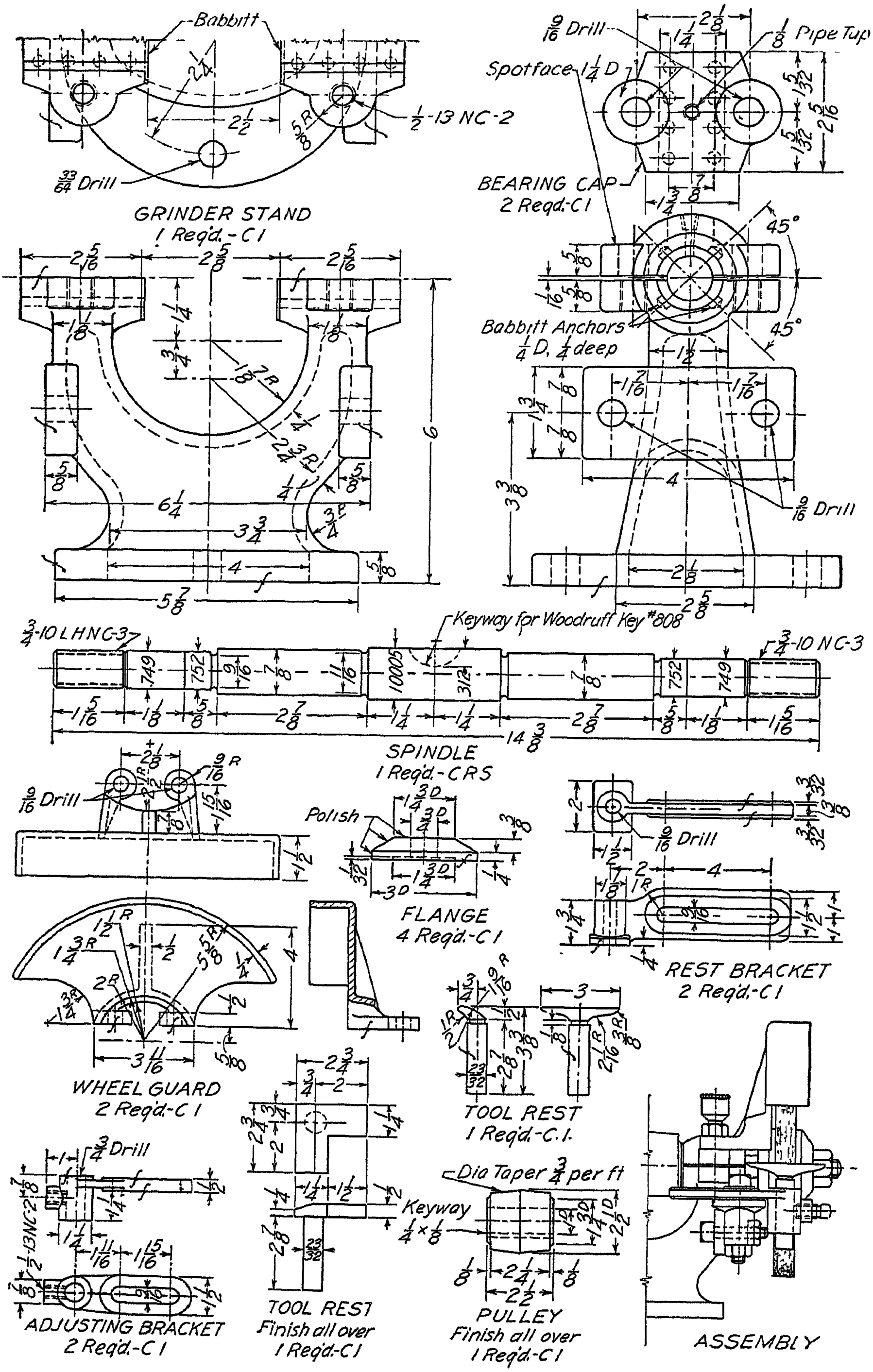


FIG. 665.—Bench grinder (see page 295).

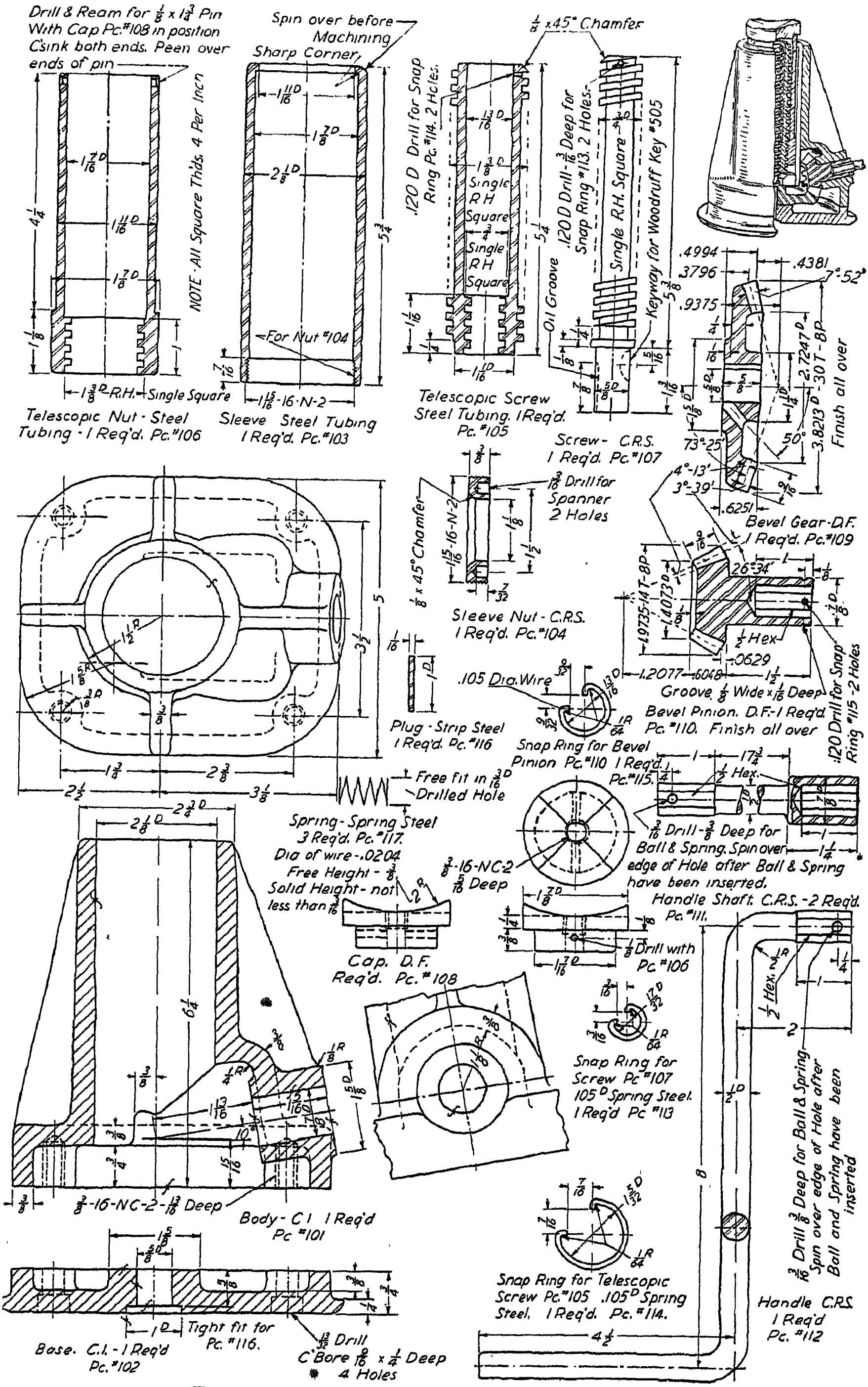


FIG. 666.—Telescopic screw jack (see page 295).

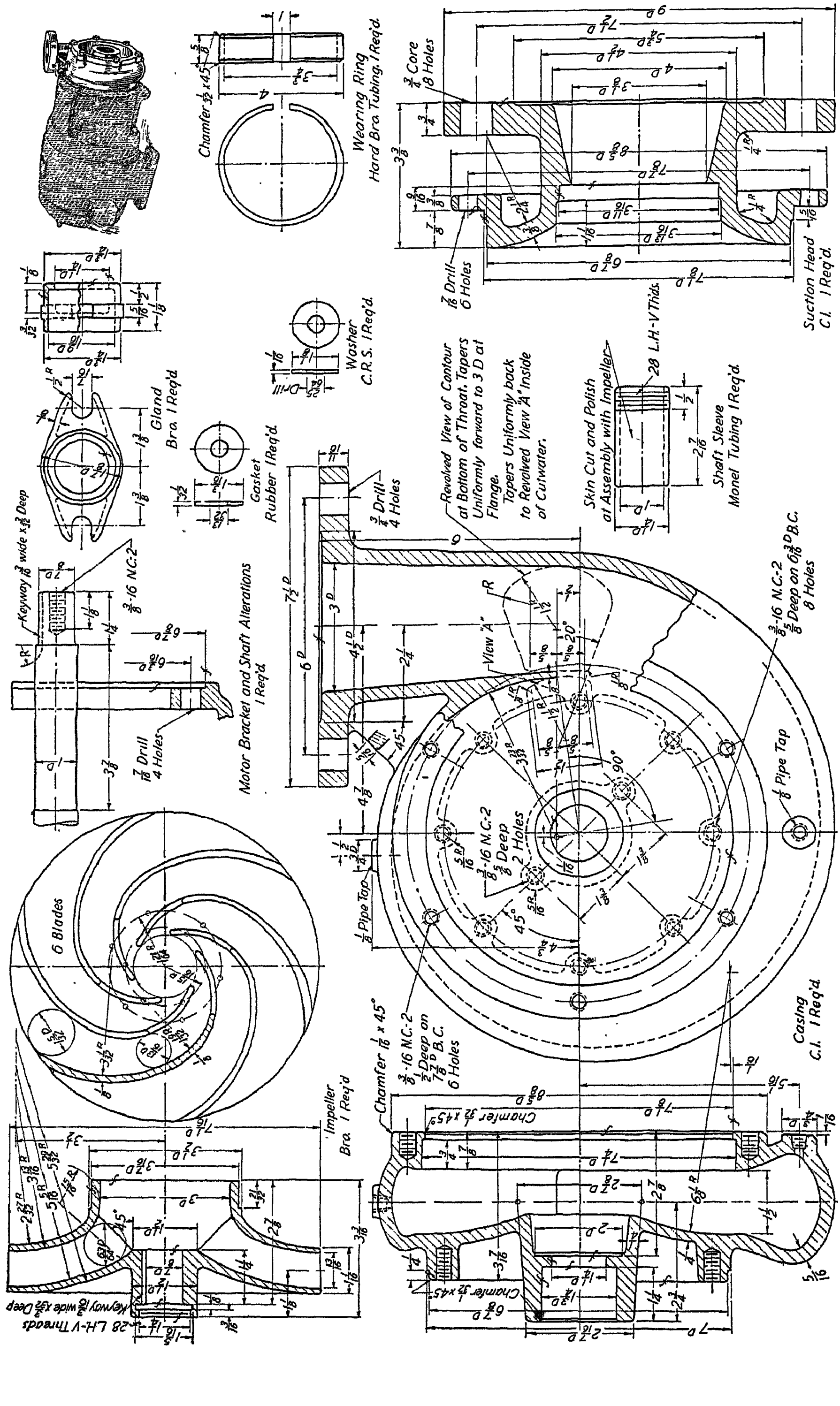


FIG. 667.—Centrifugal pump (see page 295)

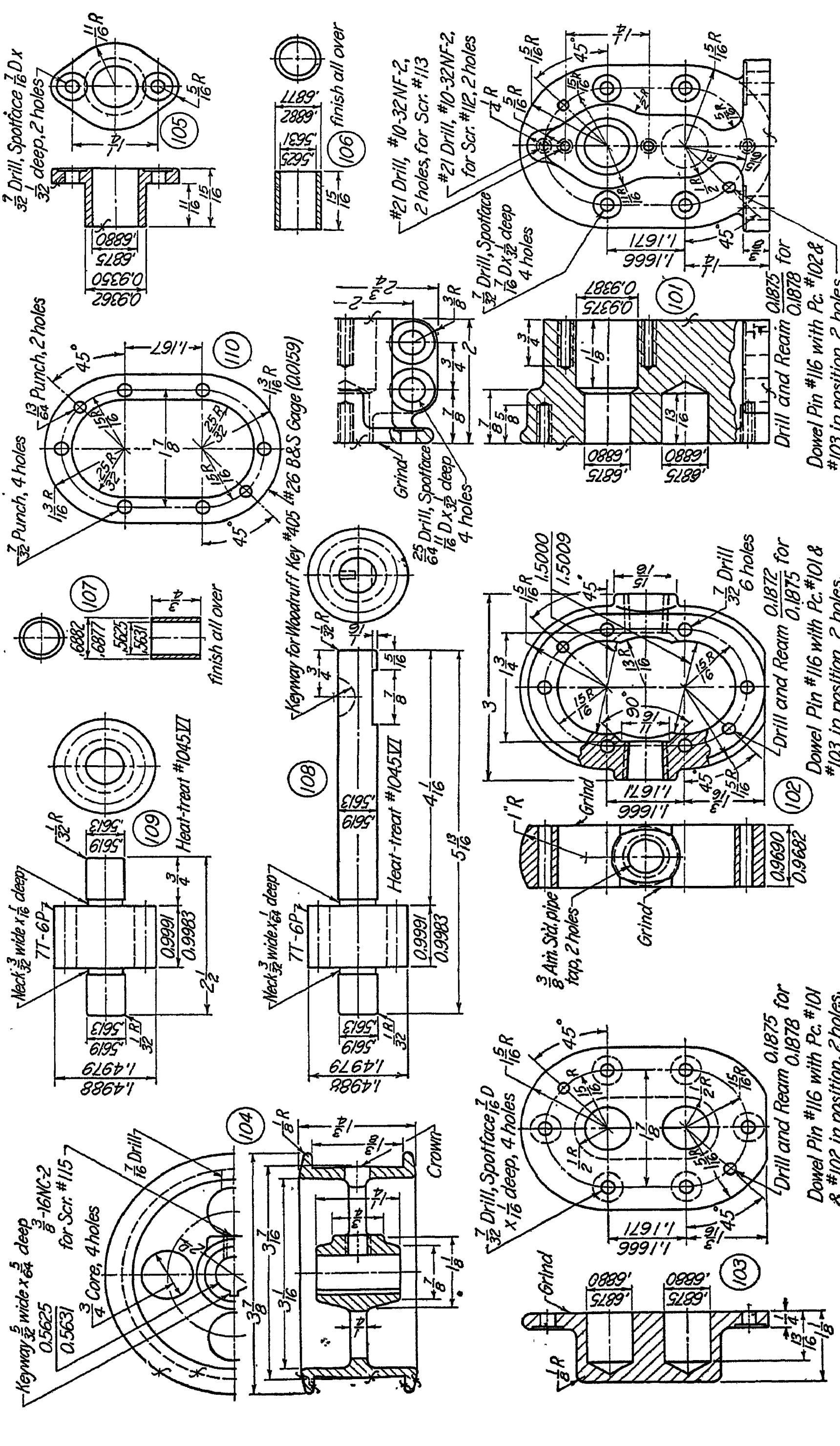


FIG. 668.—Rotary geared pump (see page 302). (Courtesy of Brown & Sharpe Mfg. Co.)

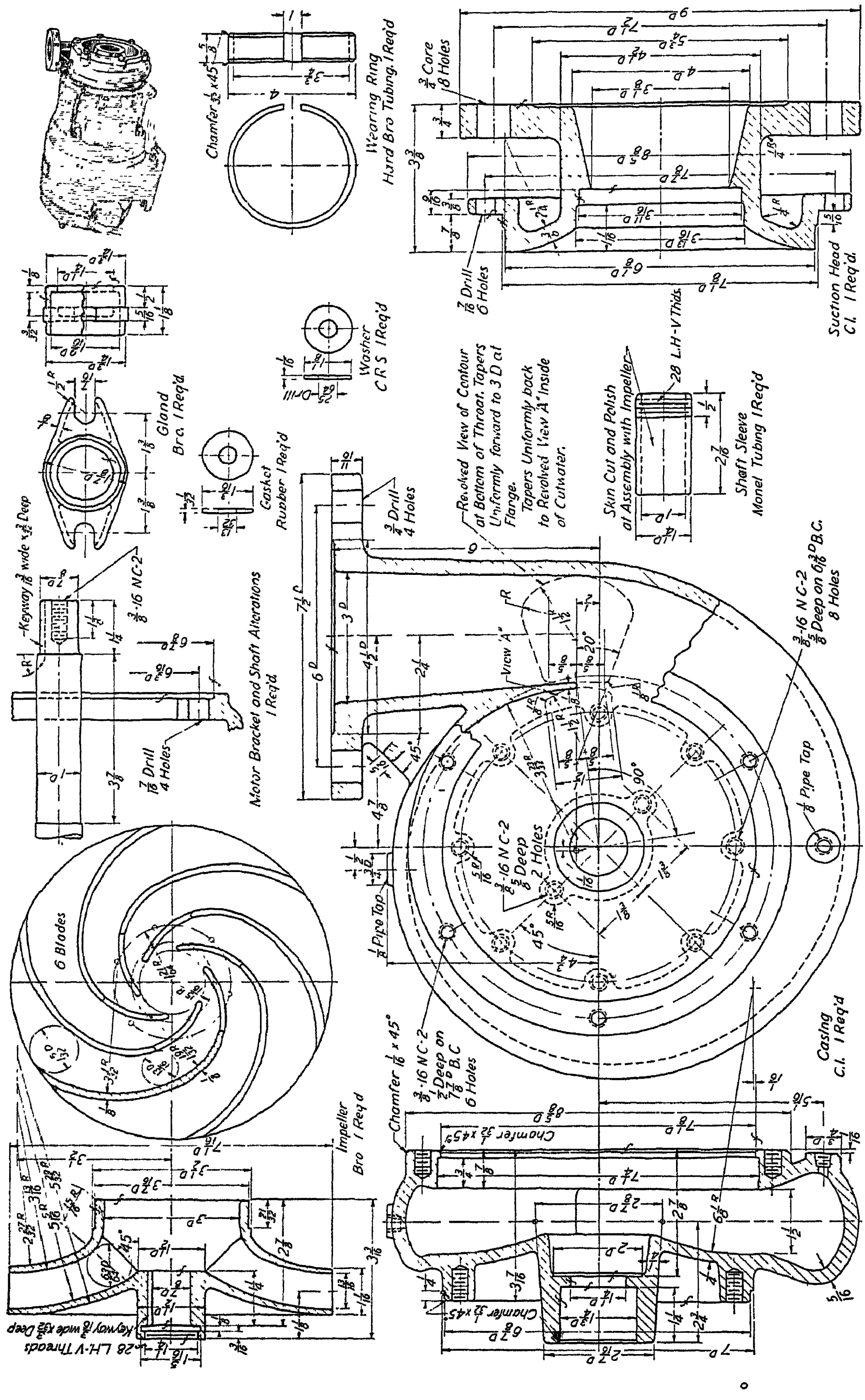


FIG. 667.—Centrifugal pump (see page 295)

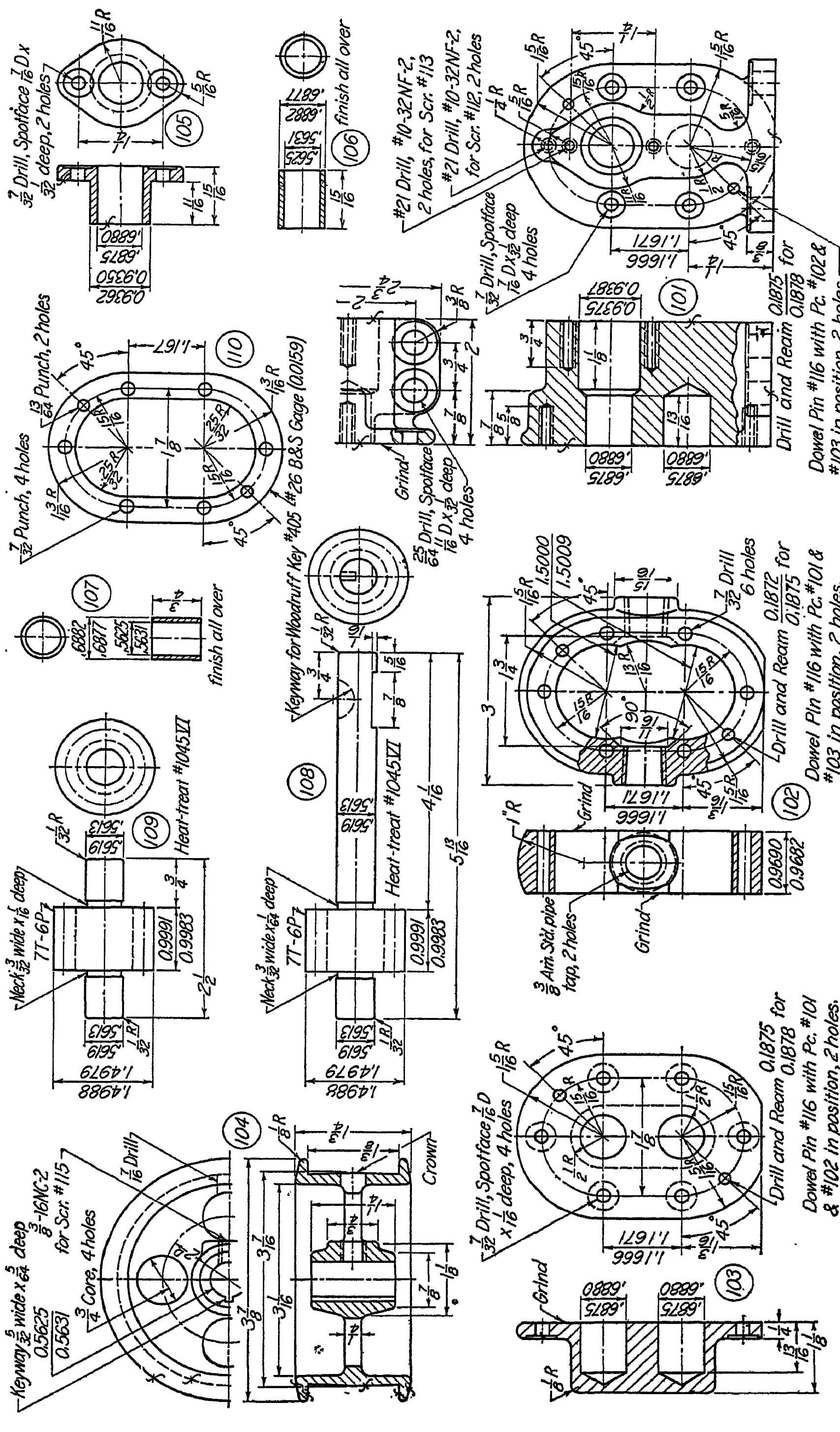


FIG. 668.—Rotary geared pump (see page 302). (Courtesy of Brown & Sharpe Mfg. Co.)

BILL OF MATERIAL

BROWN AND SHARPE No. 1 ROTARY GEARED PUMP

PC NO.	DRAW. SIZE	NAME	QUAN.	MAT	STOCK		USED ON		REMARKS
					DIA	LENG	NAME	PC NO.	
101		Base	1	C.I.					
102		Body	1	C.I.					
103		Cover	1	C.I.					
104		Pulley	1	C.I.					
105		Gland	1	C.I.					
106		Gland Bushing	1	Bro.					
107		Gear Bushing	4	Bro.					
108		Driving Gear	1	S.A.E. #1045	1 9/16	5 7/8			
109		Driven Gear	1	S.A.E. #1045	1 9/16	2 9/16			
110		Gasket	2	Sheet Copper			Body	102	#26 B&S Gage (0.0159)
111		#10-32 x 1 5/8 Slotted Hex. Hd. Mach. Scr. & Nut	4				Cover	103	
112		#10-32 x 1 5/8 Slotted Hex. Hd. Cap Scr.	2				Cover	103	
113		#10-32 x 7/8 Slotted Hex. Hd. Cap Scr.	2				Gland	105	
114		Woodruff Key #405	1				Driving Gear	108	
115		3/8 x 3/8 Headless Set Scr., 3/8-16NC-2	1				Pulley	104	
116		3/16 x 1 7/16 Dowel Pin	2	C.R.S.			Cover	103	
		Packing	To Suit						Garlock Rotopac #239

92. Fig. 668. Make an assembly drawing of the Brown and Sharpe rotary geared pump, with top view, longitudinal section and side view. Show direction of rotation of shafts and flow of liquid with arrows. Give dimensions for base holes to be used in setting; also give distance from base to center of driving shaft and size of shaft and key. Refer to Chap. XVI for method of drawing the teeth of the gears, pieces 108 and 109.

93. Fig. 669. Make detail drawings for steam-jacketed laboratory autoclave. An autoclave is a piece of chemical apparatus used where chemical action under pressure is required. It may be built with a steam jacket as in Fig. 669, or without. Stirring devices may or may not be provided, depending on the use. The autoclave shown has a 2-gallon capacity and is designed for 800 pounds working pressure.

94. Design an autoclave of 10-gallon capacity. Provide an agitator to revolve at 125 rpm driven from motor running at 1,200 rpm. Calculate size of pulley and bevel gears. Figure wall thickness for 900 pounds pressure. On steam-jacket shell add three lugs for supporting legs. Provide openings in cover for safety valve, pressure gage and thermometer well. Use T bolts, calculating area and referring to handbook for corresponding bolt size. Make complete assembly drawing.

95. Make detail drawings of autoclave from Prob. 94, including design of supporting legs.

96. Fig. 670. Make detail drawings of Corliss-engine dashpot. This is the spring type as made by the Allis-Chalmers Manufacturing Company. The high efficiency of the Corliss engine is obtained by what is known as the "trip-cut-off Corliss gear," a mechanism that opens the valve and then automatically disengages. The valve is then closed by the action of the dashpot, which, through a connecting link to the valve gear, pulls the linkage back to the closed position. Thus the spring (piece 11) is compressed when the valve is open, and extends to close the valve. The air valve (piece 7) is regulated to cushion the fall of the plunger (piece 2) and also to create a partial vacuum in the cylinder, thereby amplifying the action.

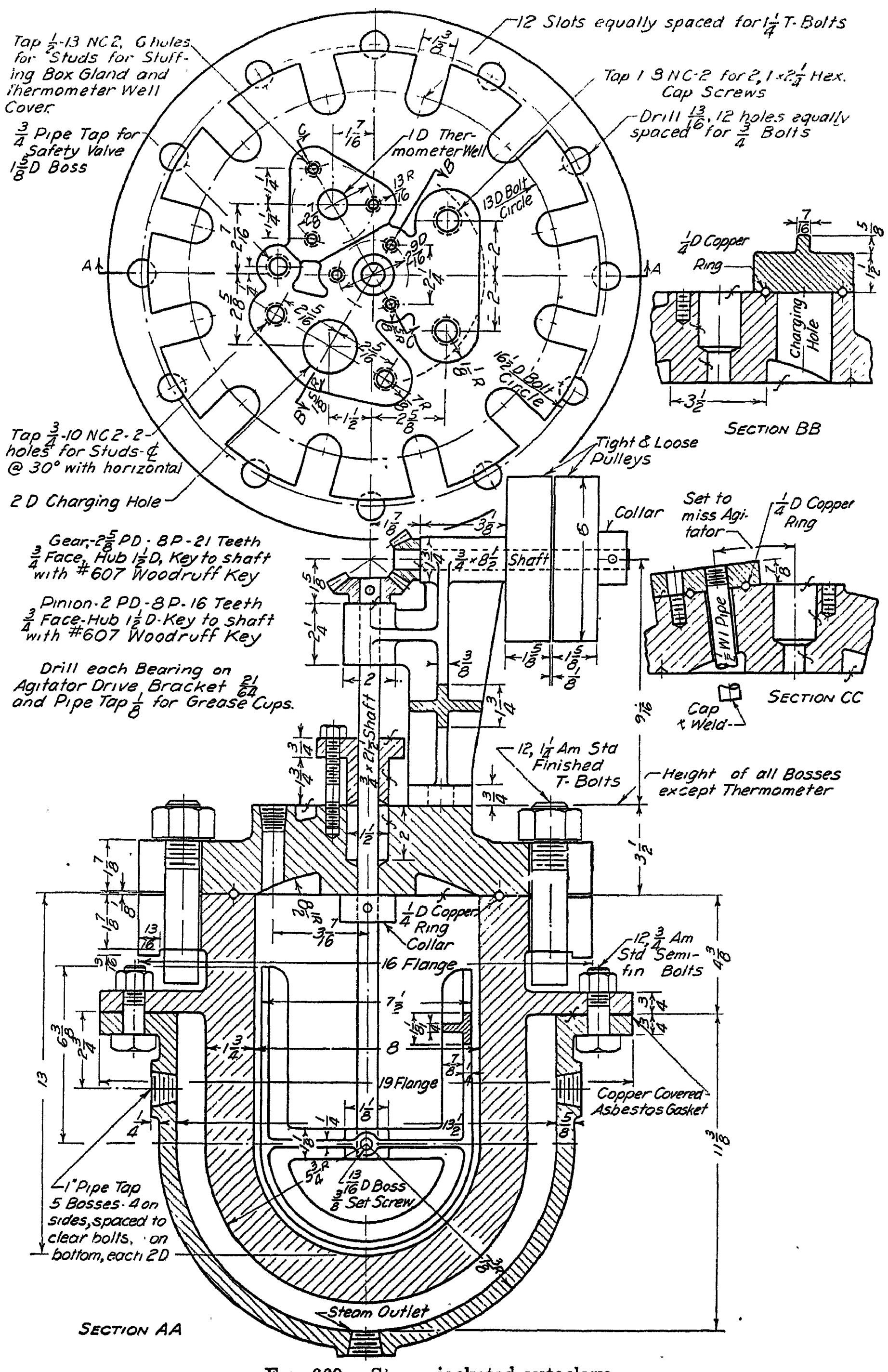
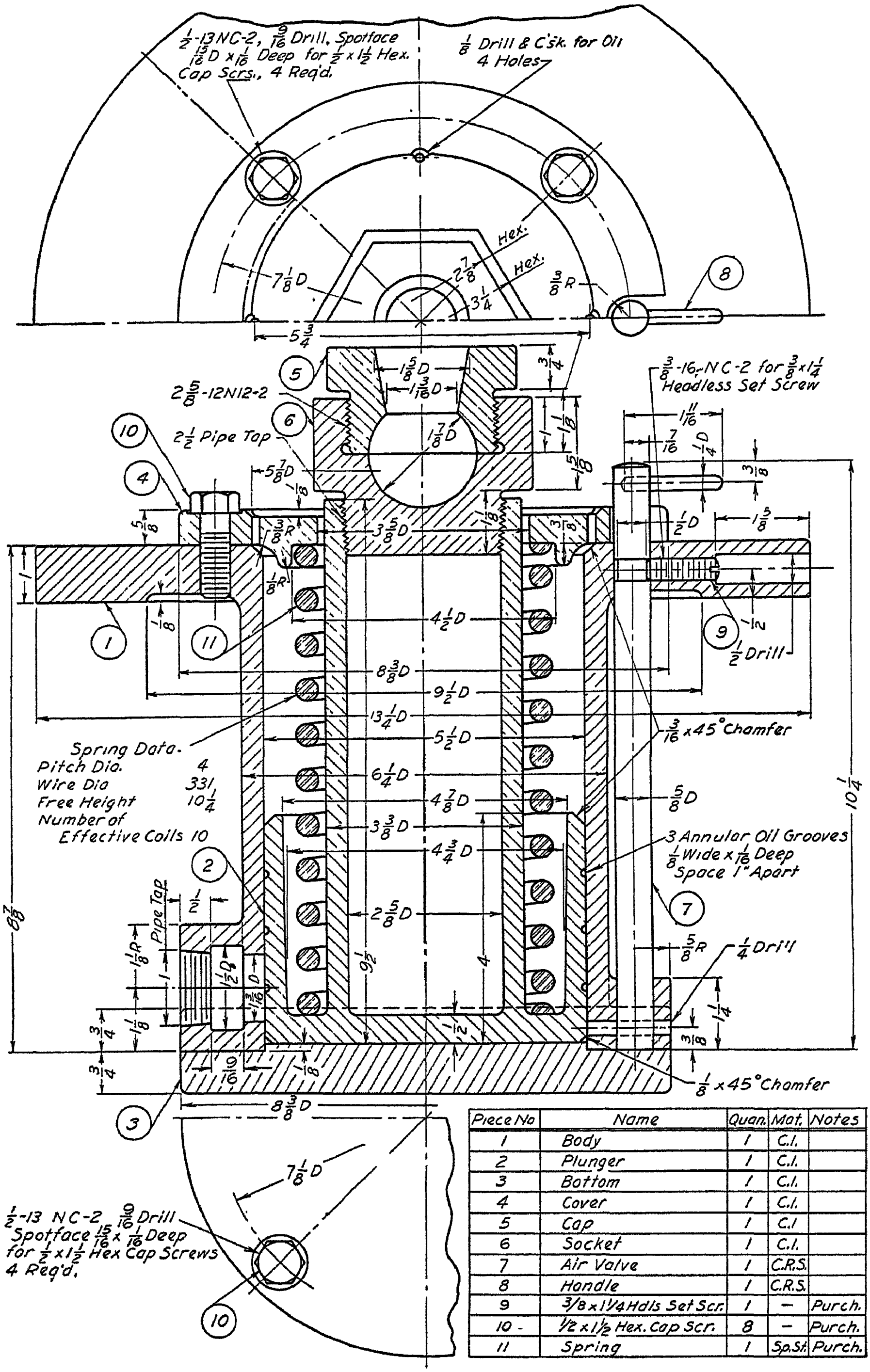


FIG. 669.—Steam-jacketed autoclave.



Piece No	Name	Quan.	Mat.	Notes
1	Body	1	C.I.	
2	Plunger	1	C.I.	
3	Bottom	1	C.I.	
4	Cover	1	C.I.	
5	Cap	1	C.I	
6	Socket	1	C.I.	
7	Air Valve	1	C.R.S.	
8	Handle	1	C.R.S.	
9	3/8 x 1 1/4 Hdls Set Scr.	1	—	Purch.
10	1/2 x 1 1/2 Hex. Cap Scr.	8	—	Purch.
11	Spring	1	Sp.St.	Purch.

FIG. 670.—Corliss-engine dashpot (see page 302).

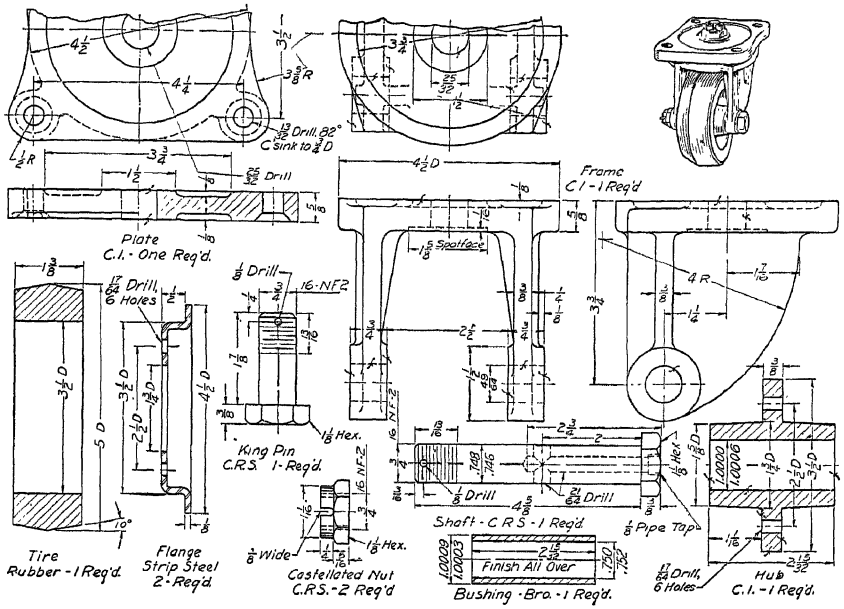


FIG. 671.—Caster.

97. Fig. 671. Make assembly drawing, front view in section, of caster.

98. Redesign caster for ball-bearing installation.

99. Fig. 672. Make detail drawings of double-acting air cylinder. Length of stroke to be assigned. Fix length of cylinder to allow for clearance of 1″ at ends of stroke. Note that pieces 101 and 102 are identical except for the extra machining of the central hole in piece 101 for the shaft, packing and gland. Make separate drawings for this piece, one for the pattern shop, and two for the machine shop.

100. Fig. 673. Make detail drawings of swing table.

101. Fig. 674. Make detail drawings of hydraulic punch. In action, the punch assembly proper advances until the cap, piece 109, comes against the work. The assembly (piece 106 and attached parts) is then stationary and the tension of the punch spring (piece 114) holds the work as the punch advances through the work and returns.

102. Redesign Fig. 674 for a punch diameter ¾″ and stroke 1½″.

103. Fig. 675. Make detail drawings of rail-transport hanger. Rail is 10-lb. ASCE.

104. Redesign Fig. 675 for 20 lb. ASCE rail. Use standard 2½″ pipe for support.

105. Fig. 676. Make detail drawings of V-belt drive.

106. Fig. 677. Make detail drawings of butterfly valve. Refer to Chap. XVI for method of detailing gear and rack.

107. Redesign Fig. 677, making butterfly 2¼″.

108. Figs. 678, 679, 680, 681. Make complete detail drawings of bench drill, with title and bill of material. The driving cone is designed to run at 400 rpm with corresponding spindle speeds of 300 and 630 rpm. The curves on head (piece 6) should be obtained by the method of Fig. 178.

109. Figs. 678 to 681. From detail drawings make assembly drawing of the bench drill, with piece numbers, bill of material and title.

110. Figs. 678 to 681. Redesign bench drill for ball-bearing installation in spindle and driving cones.

111 and **112.** (See page 309.)

PC NO	NAME	MAT	QUAN.	NOTES
101	Cylinder Head, Front	C I	1	
102	Cylinder Head, Rear	C I	1	Use Cast 101
103	Packing Gland	C I	1	
104	Piston	C.I	1	
105	Piston Rod	Steel	1	
106	Piston Plate	Steel	2	
107	Cylinder	Steel	1	Shelby Tubing
108	Tie Rod	Steel	4	
109	Stop Collar	Steel	1	
110	Piston Packing	Leath.	2	Purchase
111	Gasket	Fiber	2	Purchase

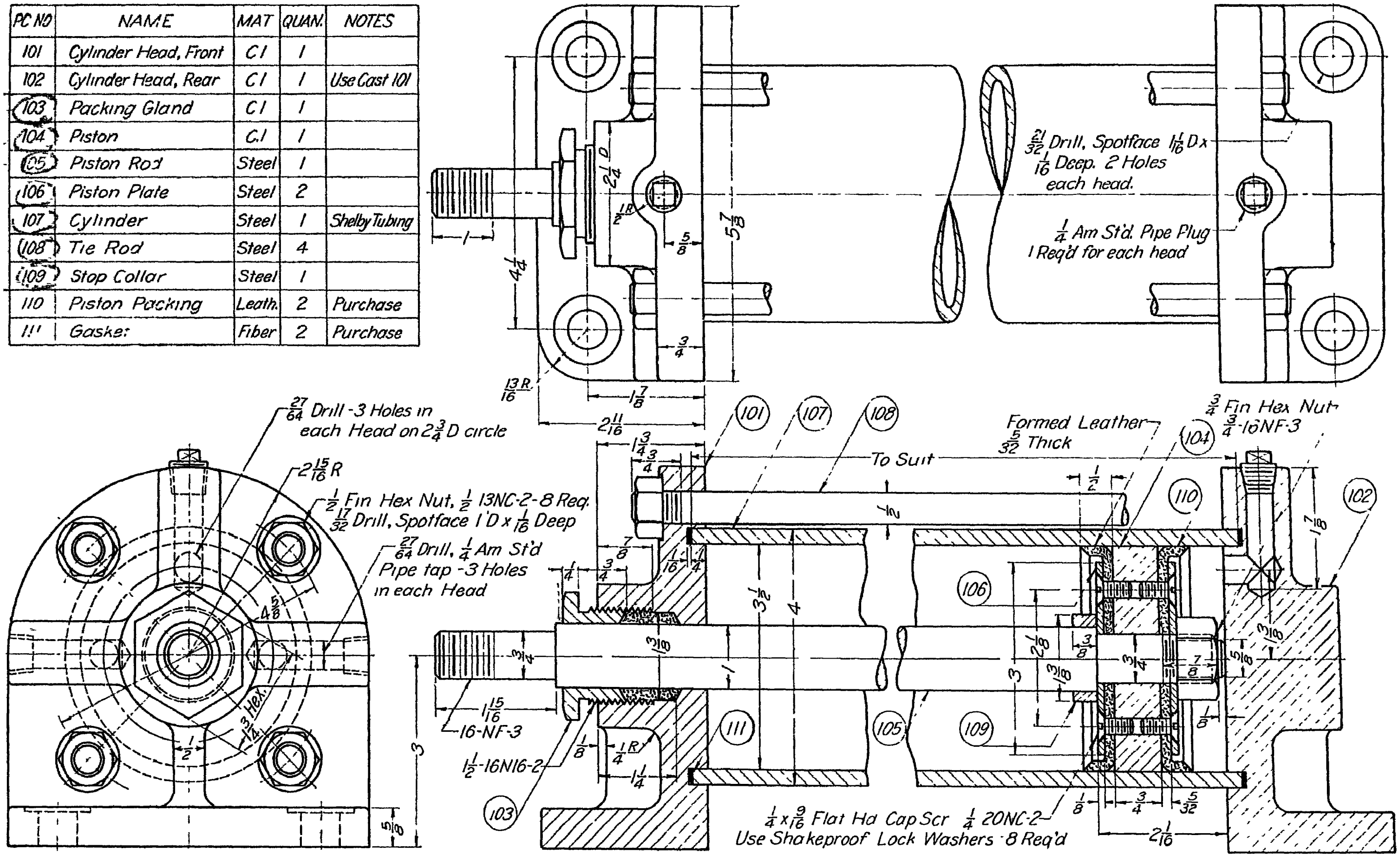


FIG. 672.—Double-acting air cylinder (see page 305).

PC NO.	NAME	MAT.	QUAN.	NOTES
101	Base	C.I.	1	
102	Table	C.I.	1	
103	Trunnion Stud	Steel	1	

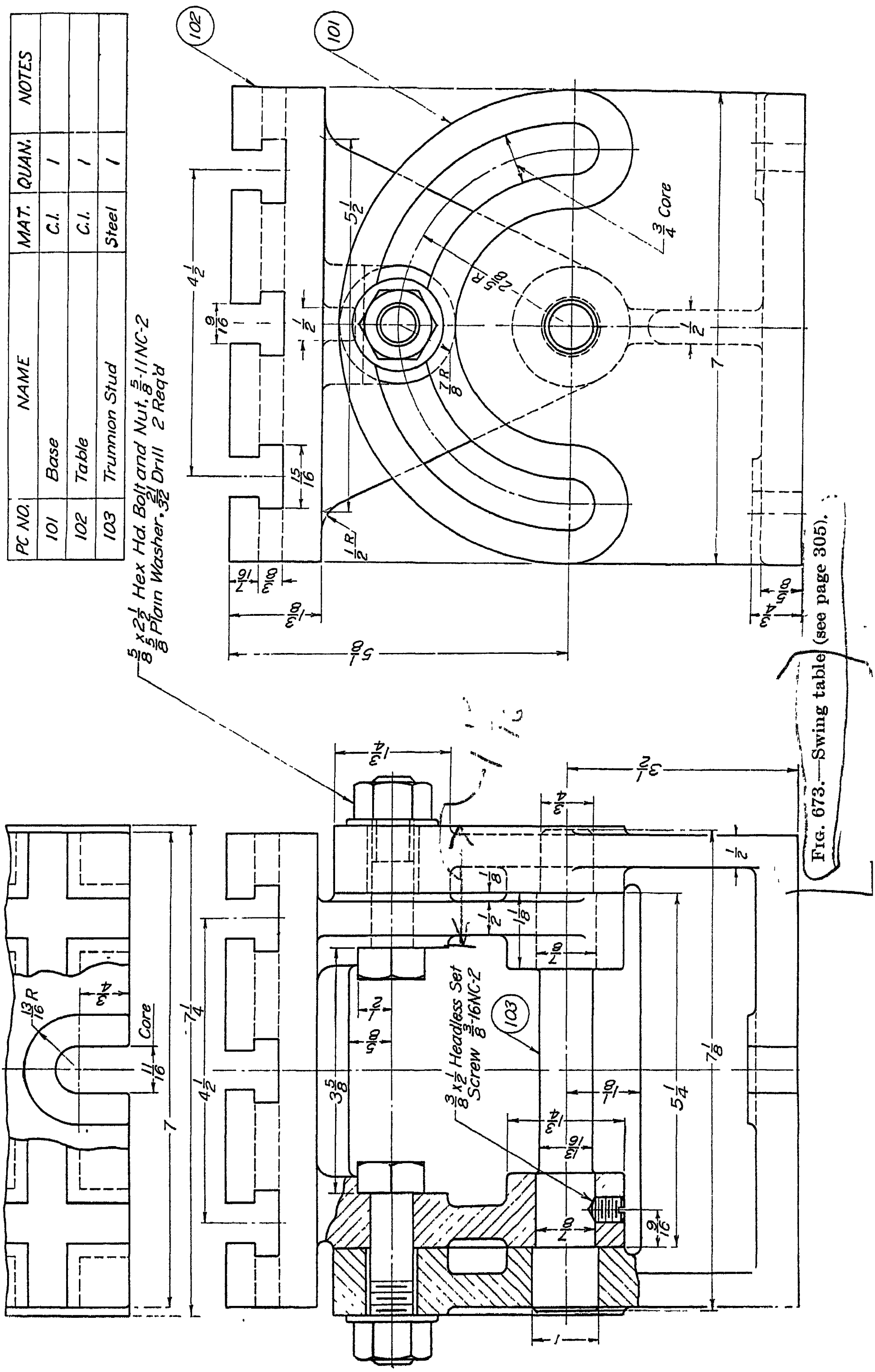
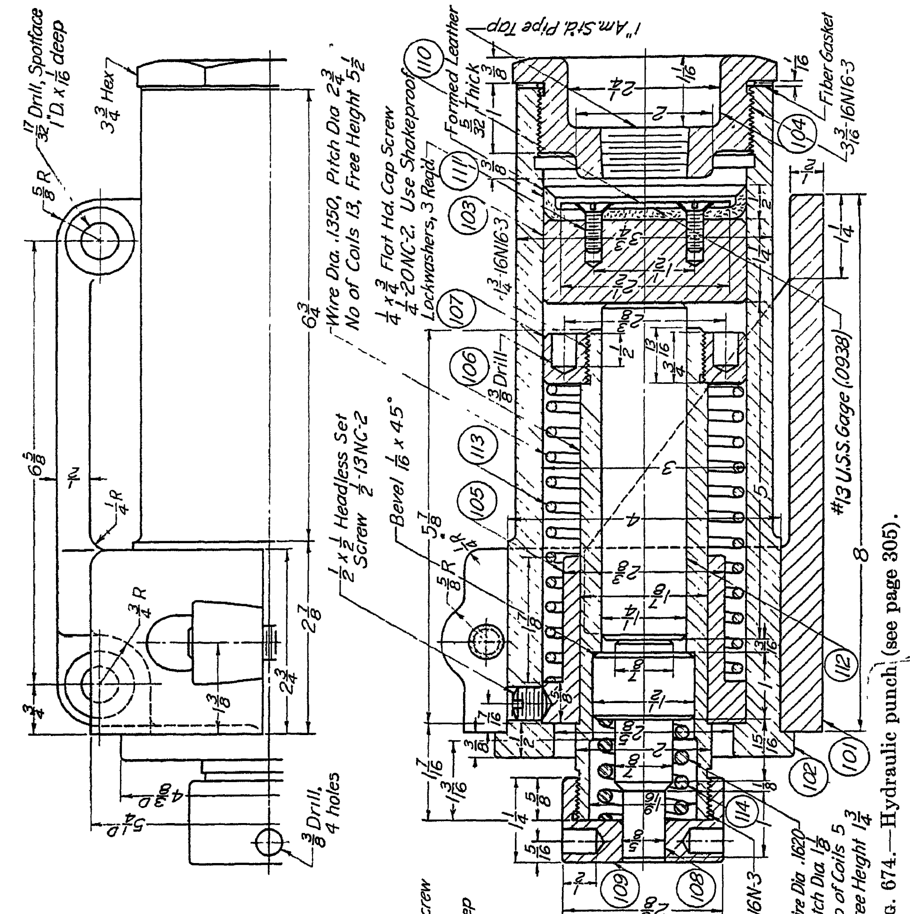


FIG. 673.—Swing table (see page 305).



PC. NO.	NAME	MAT.	QUAN.	NOTES
101	Bracket	C.I.	1	
102	Cylinder	C.I.	1	
103	Piston	C.I.	1	
104	Cylinder Head	C.I.	1	
105	Sleeve Stop	C.I.	1	
106	Sleeve	Steel	1	
107	Sleeve Nut	Steel	1	
108	Punch	Steel	1	
109	Punch Cap	Steel	1	
110	Packing Plate	Steel	1	
111	Packing	Leather	1	Purchase
112	Piston Rod	Steel	1	
113	Sleeve Spring	Steel	1	Purchase
114	Punch Spring	Steel	1	Purchase

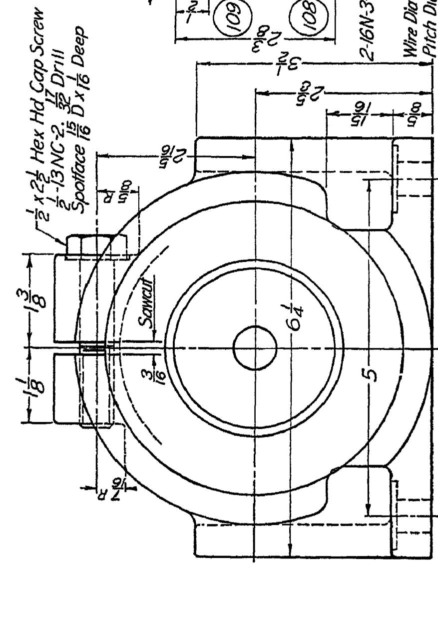
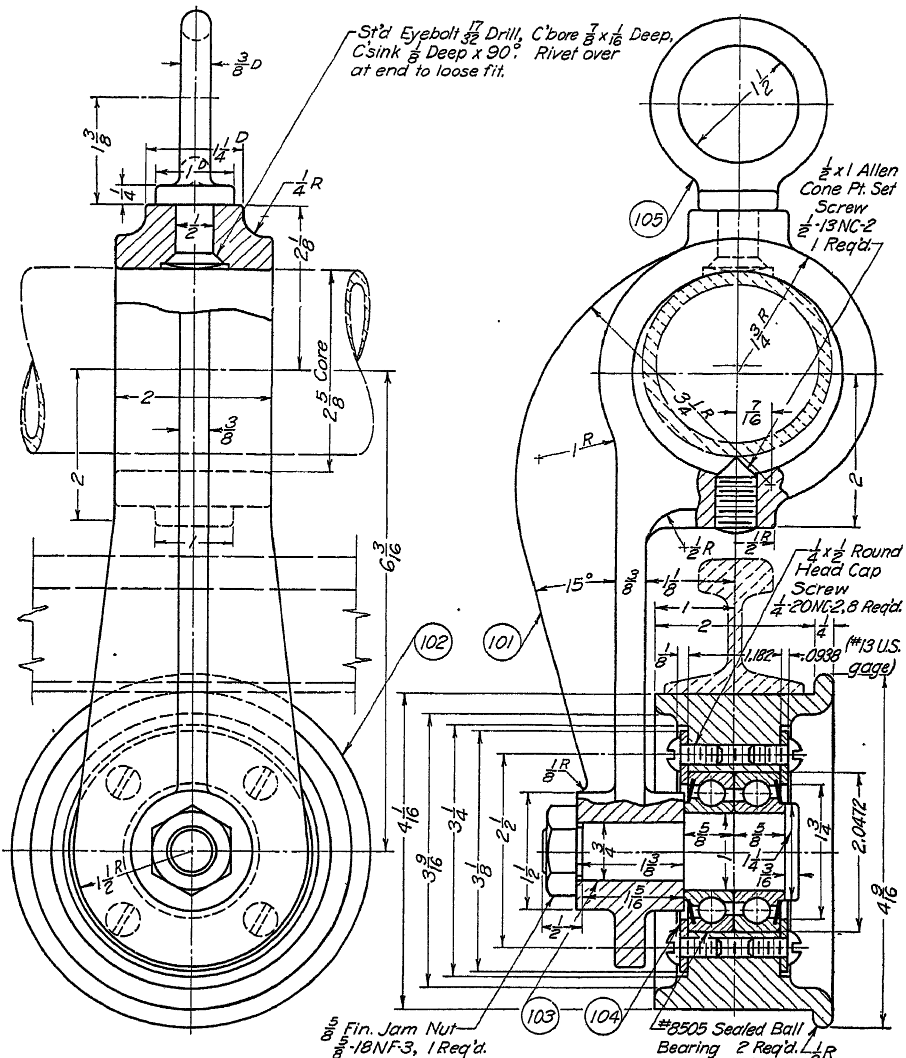


FIG. 674.—Hydraulic punch (see page 305).



PC. NO.	NAME	MAT.	QUAN.	NOTES
101	Hanger	C.S.	1	
102	Wheel	C.I.	1	
103	Stud	Steel	1	
104	Plate	Steel	2	#13 U.S. Gage (.0938)
105	Eyebolt	D.F.	1	Purchase

FIG. 675.—Rail-transport hanger (see page 305).

111. Figs. 678 to 681. Redesign bench drill as follows: spindle-cone diameters, $5\frac{7}{16}''$ and $7\frac{7}{16}''$; driving-cone diameters, $6\frac{5}{8}''$ and $8\frac{9}{16}''$. Note that this will change the position of the belt-shifter bracket and the idler pulleys. Check for interference with the driving cone and knee.

112. Figs. 678 to 681. Redesign bench drill for a loose pulley speed of 350 rpm and spindle speeds of 600 and 325.

PC. NO.	NAME	MAT.	QUAN.	NOTES
101	Bracket	C.I.	1	
102	Gear	C.I.	1	
103	Shaft	Steel	1	
104	Gland	C.I.	1	
105	Pulley	Al.	1	Die Cast
106	Bushing	Bro.	1	

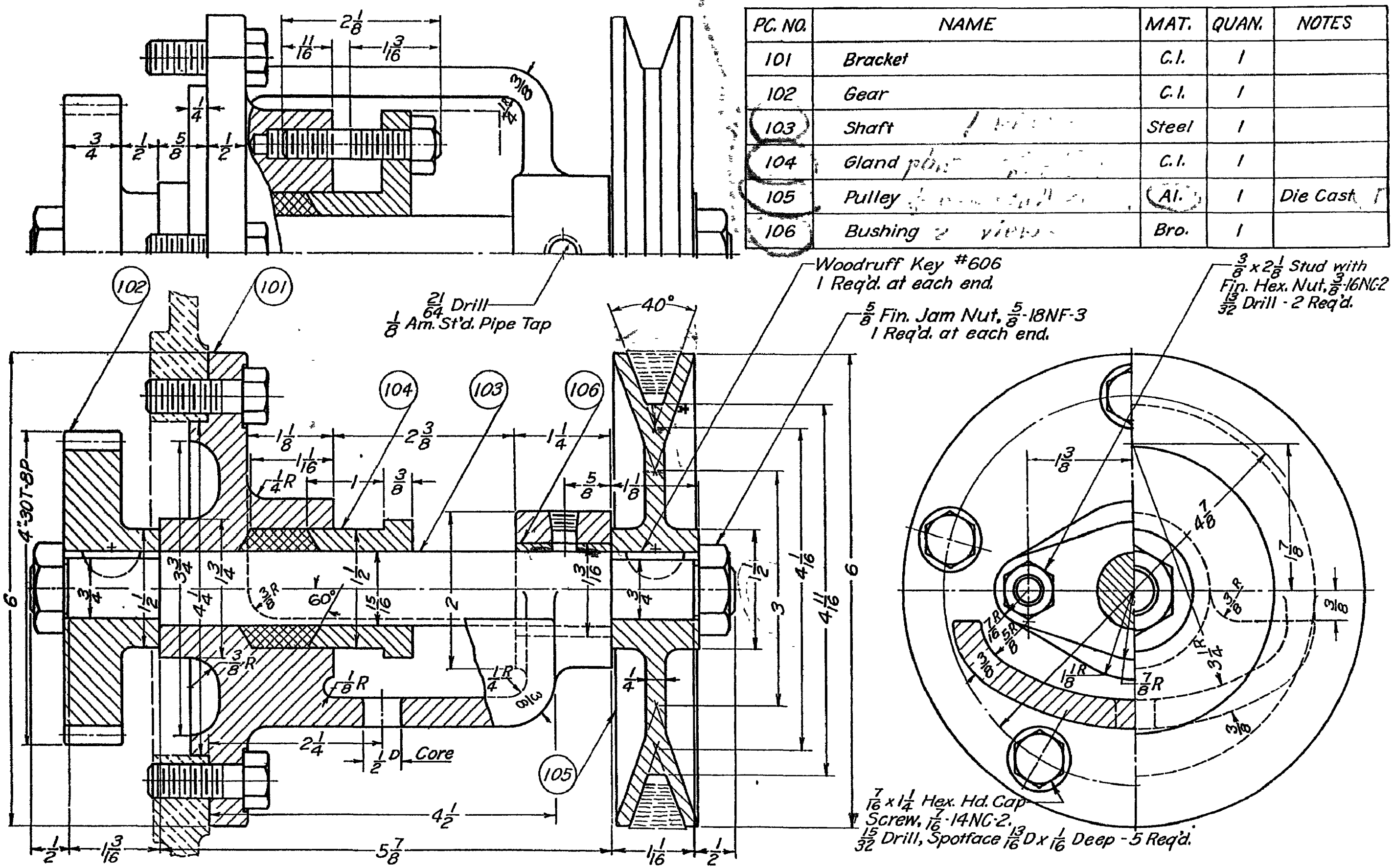
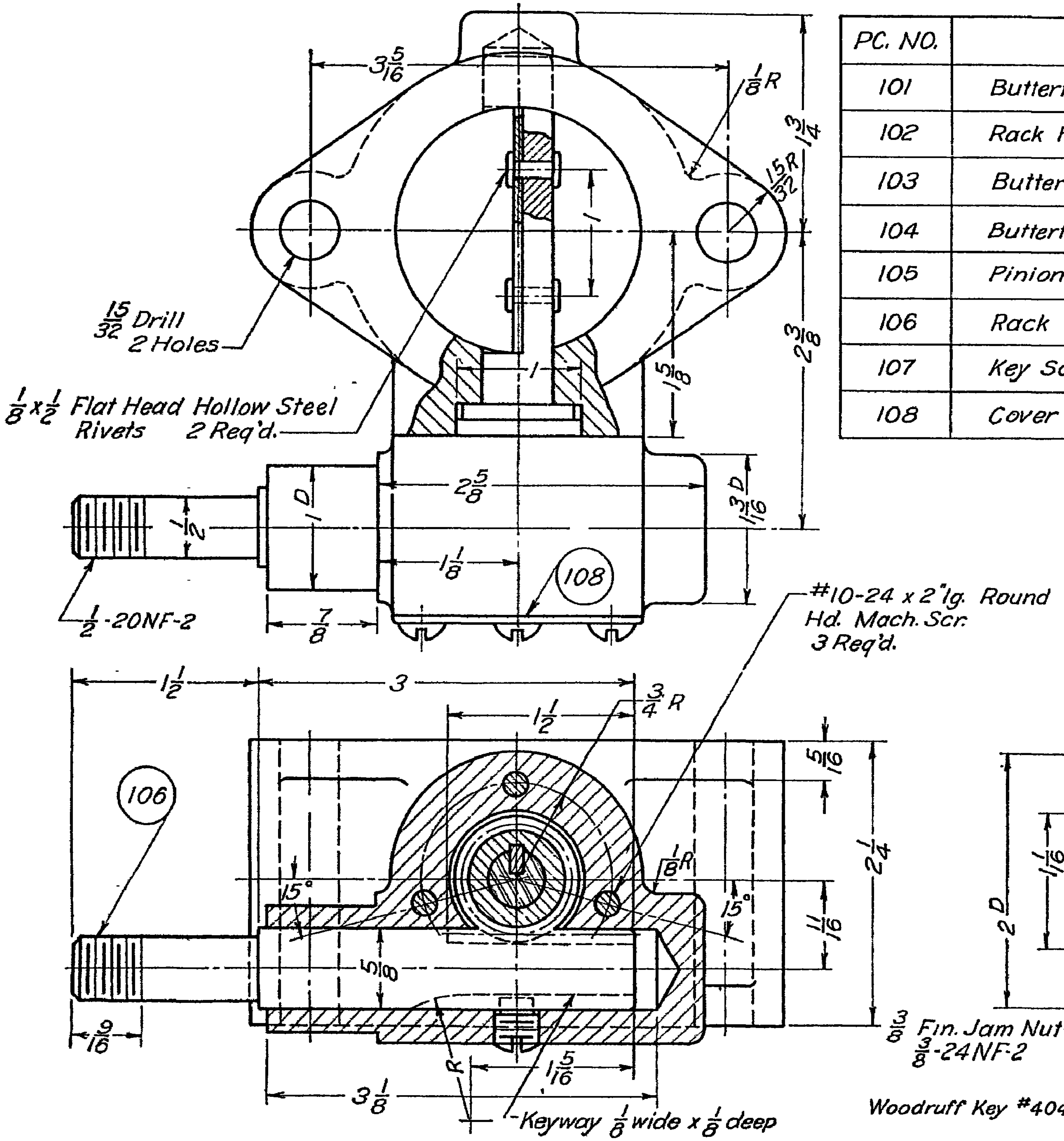


FIG. 676.—V-belt drive (see page 305).

PC. NO.	NAME	MAT.	QUAN.	NOTES
101	Butterfly Housing	Mal. I.	1	
102	Rack Housing	Mal. I.	1	
103	Butterfly (.0625" thick)	Steel	1	#16 U.S.S. Gage
104	Butterfly Shaft	Steel	1	
105	Pinion	Steel	1	
106	Rack	Steel	1	16 Pitch
107	Key Screw	Steel	1	
108	Cover (.0625" thick)	Steel	1	#16 U.S.S. Gage



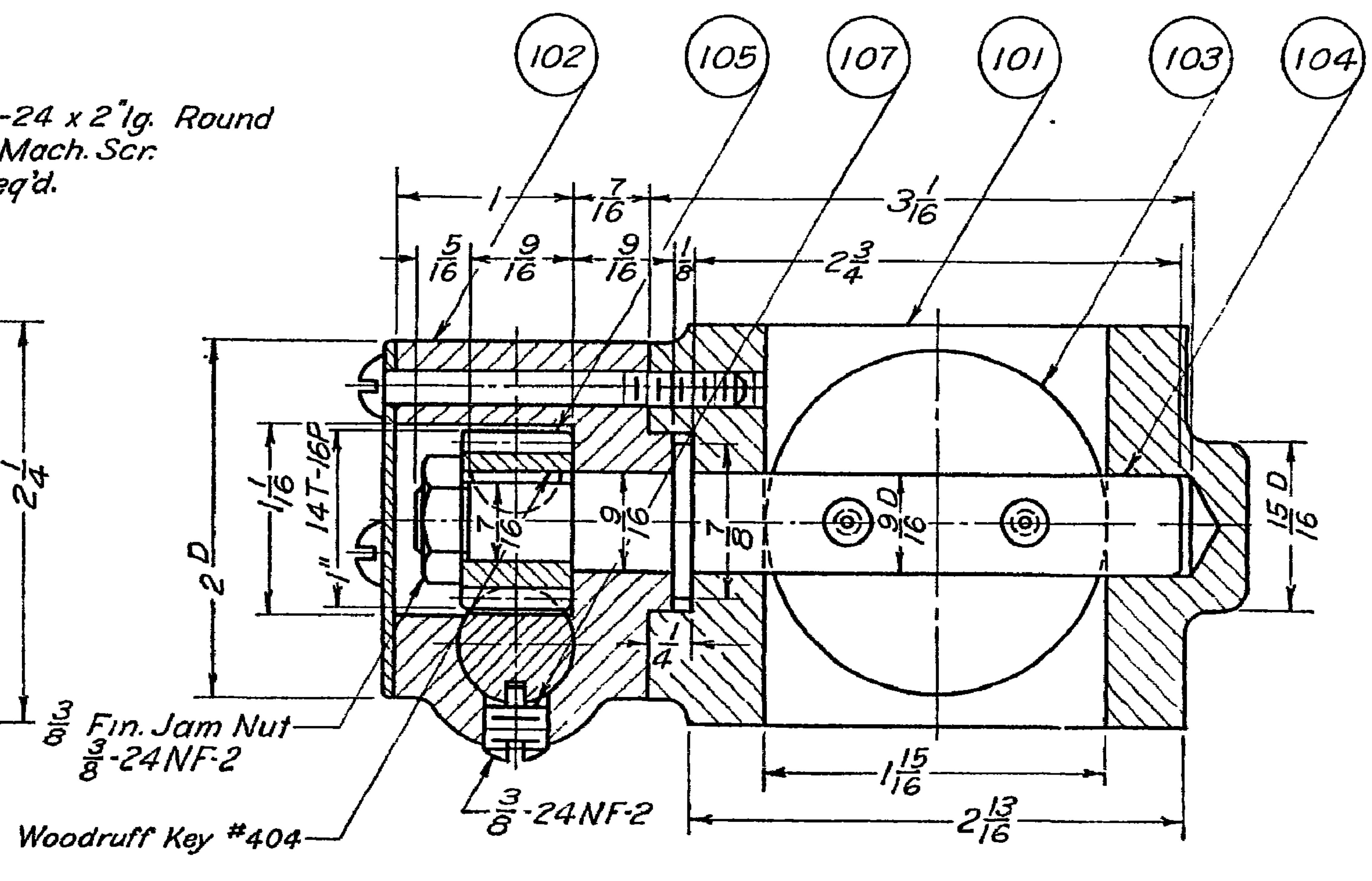
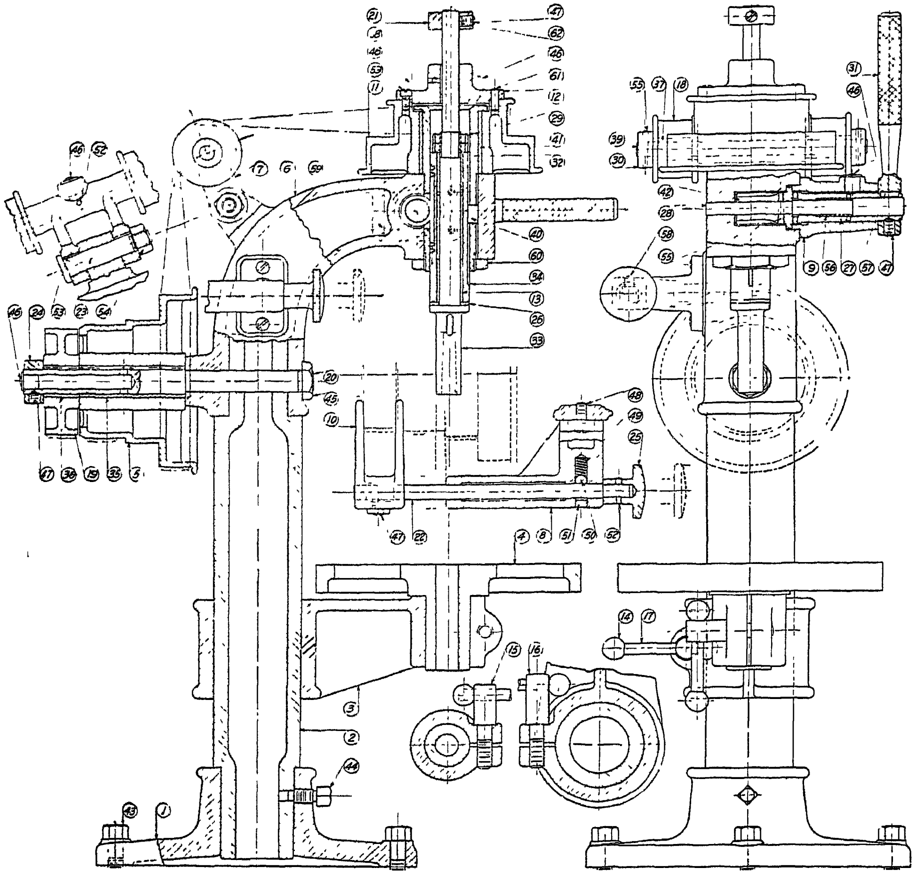


FIG. 677.—Butterfly valve (see page 305).



BILL OF MATERIAL

Pc No	Name	Q	Mat	Pc No	Name	Q	Mat	Purchased Finished Pc No	Name	Q	Used On Name	Pc No
1	Base 1	1	CI	31	Hand Lever 2	1	Steel Forg	43	[illegible] Hex Cap Scrw	4	Base	1
2	Column 1	1	CI	32	Spindle Cone Sleeve 3	1	MS	44	[illegible] x 1 Dog Pt Set Scrw	1	Base	1
3	Knee 1	1	CI	33	Spindle 3	1	[illegible]	45	[illegible] Hex Nut [illegible] Thick	1	Driving Cone Shft	20
4	Table 2	1	CI	34	Spindle Sleeve 3	1	MS	46	[illegible] Ball & Sprg Oiler	1	Driving Cone Shft	20
5	Driving Cone 2	1	CI	35	Driving Cone Bush 3	1	Bro	46	[illegible] Ball & Sprg Oiler	1	Idler Pulley Frame	7
6	Head 1	1	CI	36	Loose Pulley Bush 3	1	Bro	46	[illegible] Ball & Sprg Oiler	1	Hand Lever Bracket	9
7	Idler Pulley Frame 1	1	CI	37	Idler Pulley Bush 3	2	Bro	46	[illegible] Ball & Sprg Oiler	2	Driving Flange	12
8	Belt Shifter Bracket 2	1	CI	38	Spindle Key 2	1	[illegible]	47	[illegible] Hdlss Set Scrw	1	Driving Shft Collar	24
9	Hand Lever Bracket 2	1	CI	39	Idler Pulley Shaft 2	1	CRS	47	[illegible] Hdlss Set Scrw	1	Belt Shifter	10
10	Belt Shifter 2	1	CI	40	Spindle Sleeve Key 3	1	CRS	47	[illegible] Hdlss Set Scrw	1	Hand Lever	31
11	Spindle Cone 2	1	CI	41	Spindle Cone Bush 3	1	Bro.	47	[illegible] Hdlss Set Scrw	1	Spdle Stop Collar	21
12	Driving Flange 3	1	CI.	42	Pinion 2	1	MS	48	[illegible] Fill Hd Cap Scrw	2	Belt Shifter Bracket	8
13	Spindle Bushing 2	2	Bro					49	Spring [illegible] OD 1" Long	1	Belt Shifter Bracket	8
14	Clamp Handle Ball 3	1	CRS					50	[illegible] Steel Ball	1	Belt Shifter Bracket	8
15	Table Clamp 3	1	CRS					51	[illegible] x [illegible] Cork Plug	1	Belt Shifter Bracket	8
16	Knee Clamp 3	1	CRS					52	#2 Taper Pin 1" Long	1	Belt Shifter Knob	25
17	Clamp Handle 2	2	CRS					52	#2 Taper Pin 1" Long	1	Idler Pulley Frame	7
18	Idler Pulley 2	2	CI					53	#404 Woodruff Key	1	Idler Pulley Frame Std	23
19	Loose Pulley 2	1	CI					54	[illegible] Std Hex Nut	1	Idler Pulley Frame Std	23
20	Driving Cone Shaft 3	1	CRS					55	#2 Taper Pin [illegible]" Long	2	Idler Pulley Shft Collar	30
21	Spindle Stop Collar 3	1	CRS					55	#2 Taper Pin [illegible]" Long	1	Pinion	42
22	Belt Shifter Rod 3	1	CRS					56	Spring [illegible] OD 2" Long	1	Hand Lever Clutch	27
23	Idler Pulley Frame Stud 3	1	MS					57	#5 P&W Key	1	Hand Lever Clutch	27
24	Driving Cone Shaft Collar 3	1	CRS					58	[illegible] Ball & Sprg Oiler	1	Belt Shifter Brkt	8
25	Belt Shifter Knob 3	1	CRS					59	[illegible] x [illegible] Fill Hd Cap Scrw	4	Hand Lever Brkt	9
26	Spindle Washer 3	1	Red Fiber					59	[illegible] x [illegible] Fill Hd Cap Scrw	4	Driving Flange	12
27	Hand Lever Clutch 3	1	MS					60	[illegible] Hex Nut [illegible] Thk 16 USF Thd	1	Spdle Cone Sleeve	32
28	Hand Lever Shaft 3	1	CRS					61	[illegible] x [illegible] Straight Pin	1	Driving Flange	12
29	Spindle Nut 3	2	CRS					62	[illegible] x [illegible] B'ss Plug	1	Spindle Stop Collar	21
30	Idler Pulley Shaft Collar 3	2	CRS									

FIG. 678.—Assembly and bill of material of bench drill (see page 305).

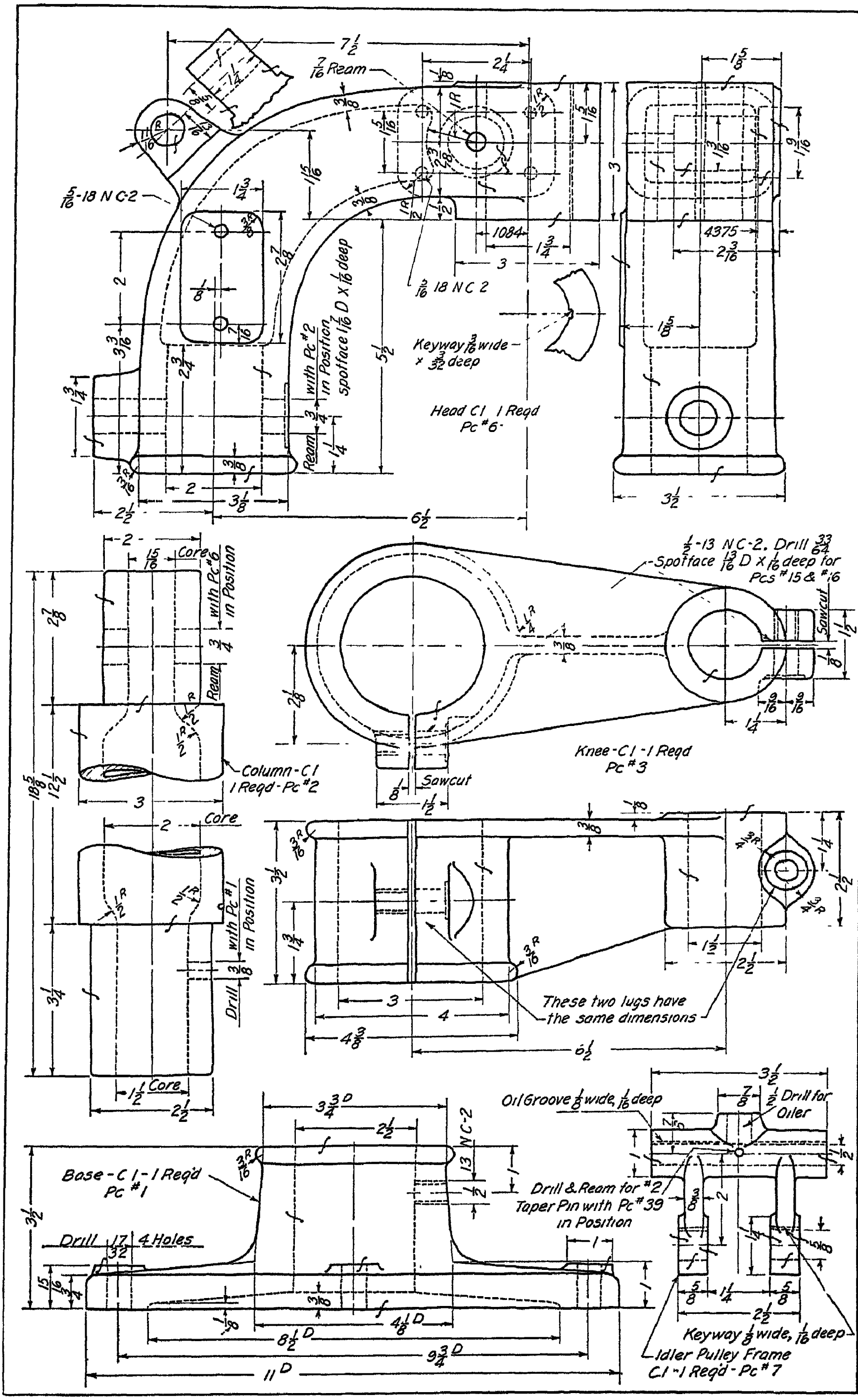


FIG. 679.—Detail sketches of bench drill.

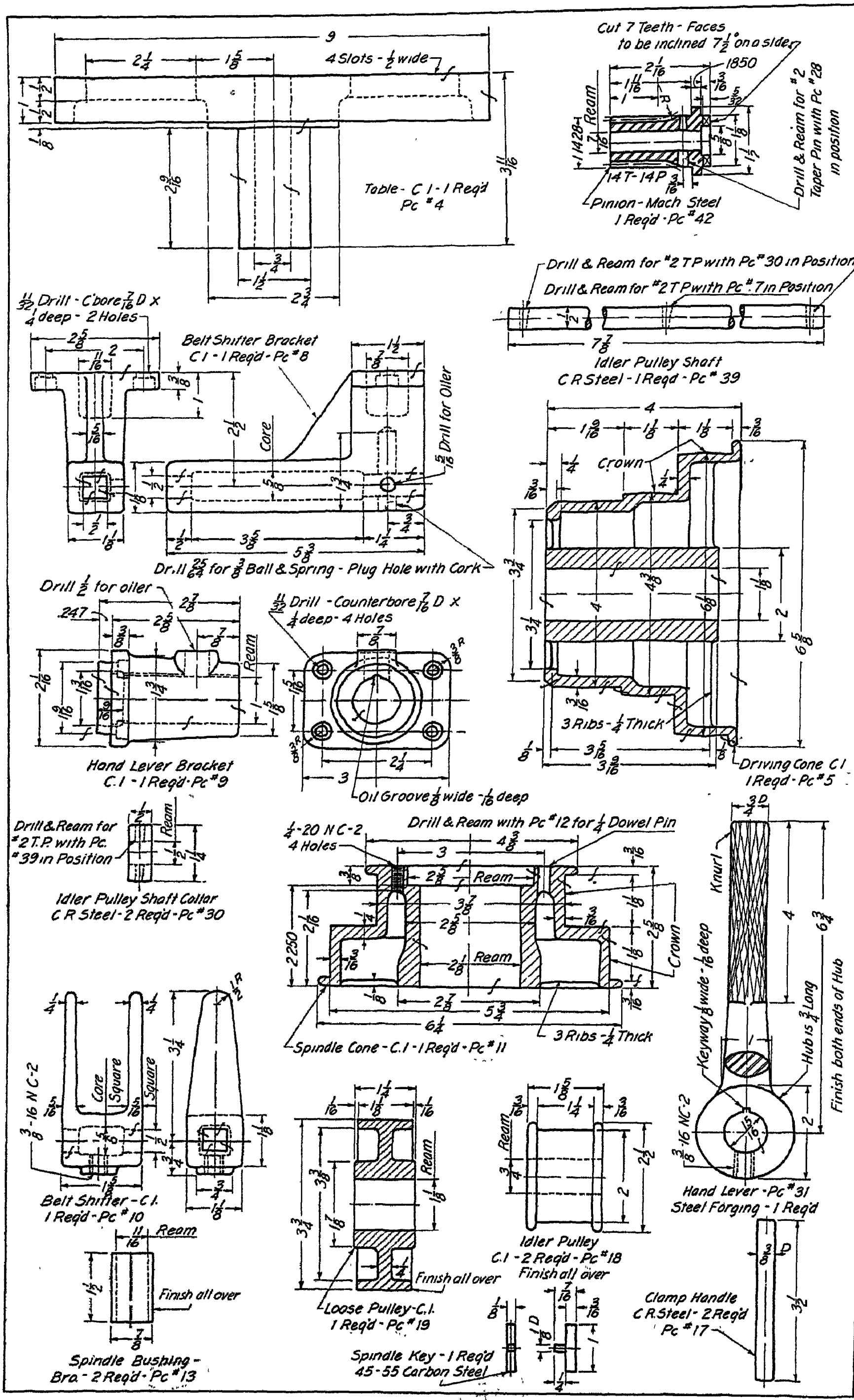


FIG. 680.—Detail sketches of bench drill.

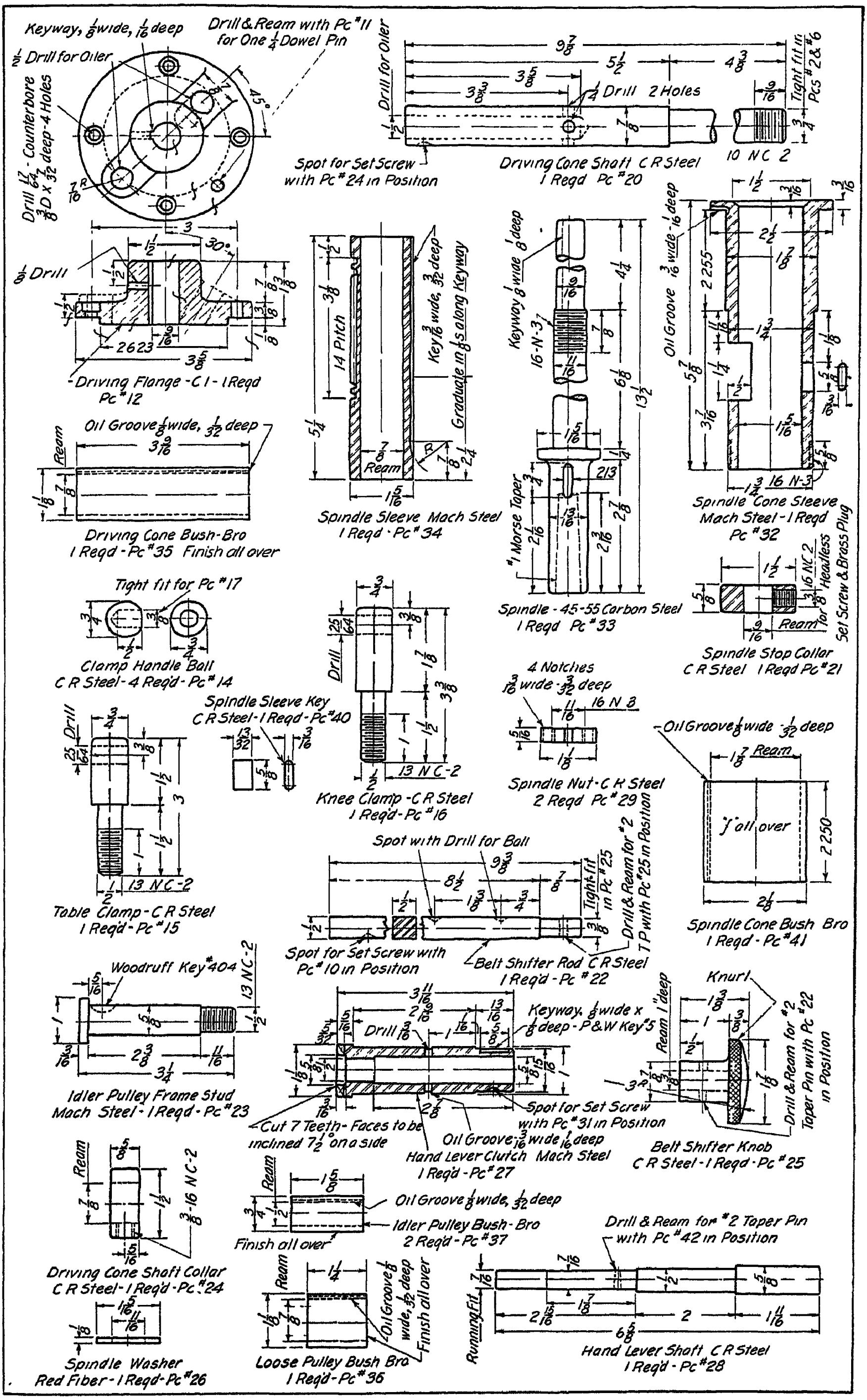


FIG. 681.—Detail sketches of bench drill.

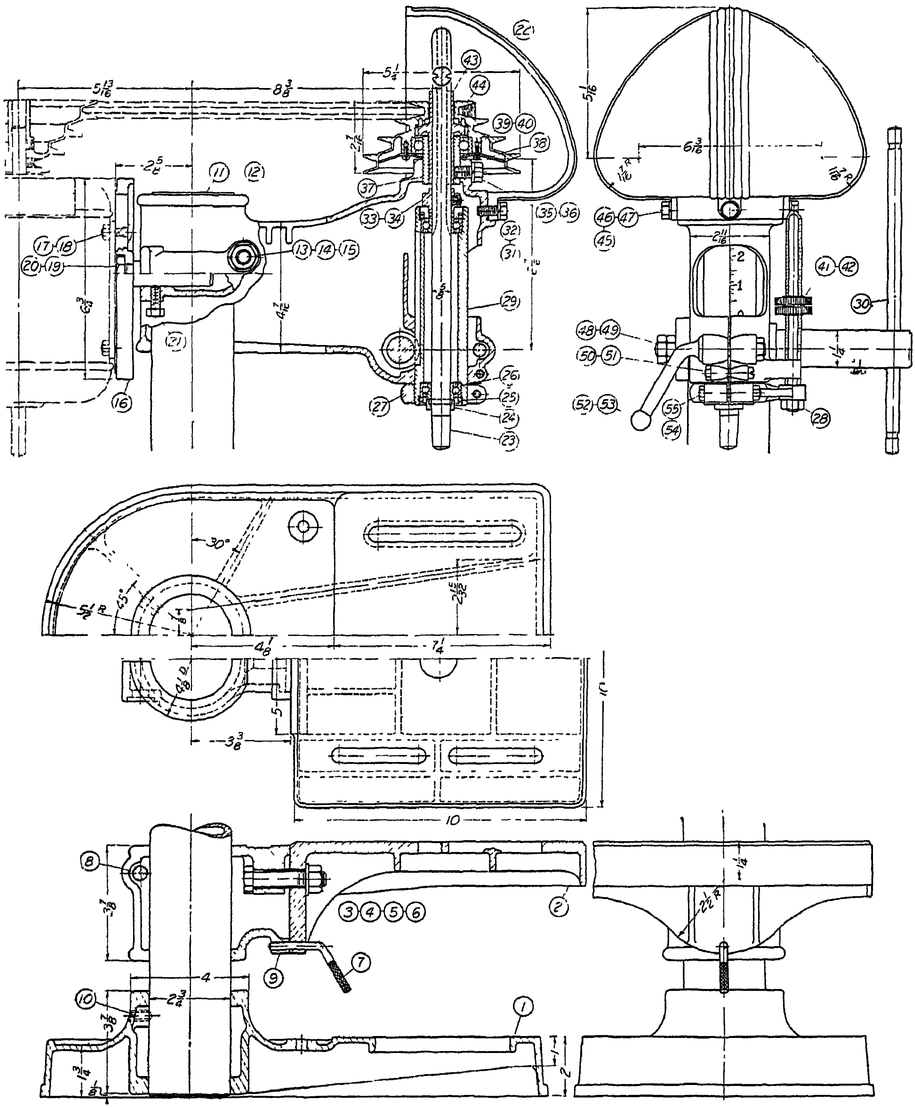


FIG. 682.—Design sketch of drill press. (*Courtesy of Delta Company.*)

113. Fig. 682. Make a complete assembly drawing of the drill press from design sketch given. Design spring return for spindle.

114. Make detail drawings and bill of material from assembly drawing,. Prob. 113.

Electrical Problems

The following problems include assembly, detail and diagrammatic drawings of electrical subjects. Some of them involve design work, in which handbooks and catalogues of electrical equipment will be required. For the diagrammatic drawings refer to the symbols in the Appendix.

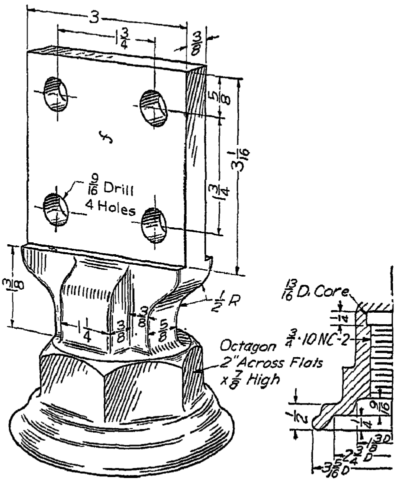


FIG. 683.—Terminal cap.

115. Fig. 683. Make detail drawing of four-bolt bar terminal cap. Cast brass.

116. Fig. 684. Make assembly and detail drawings of motor base for a 3-horsepower motor. Include a ⅜" machine screw for sliding adjustment, two adjustment bars (to be designed), hold-down bolts for motor, and guide washers (to be designed) to prevent slewing.

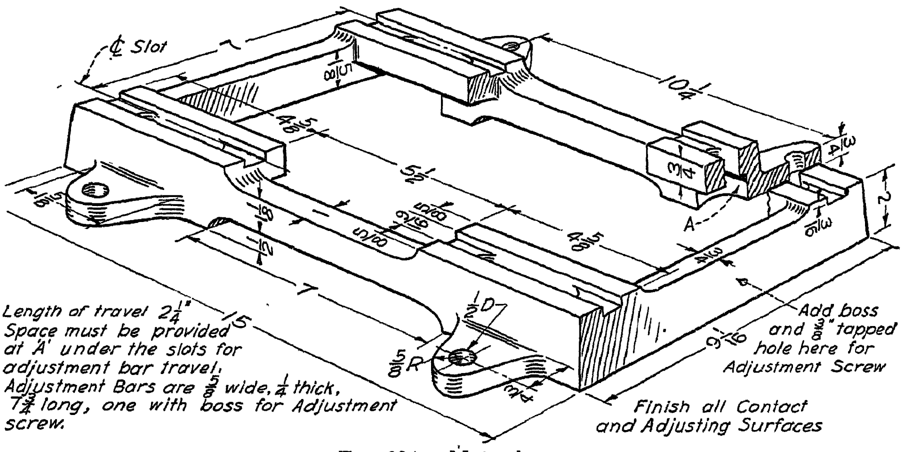


FIG. 684.—Motor base.

117. Fig. 685. From the details given, make an assembly drawing of the immersion heater, adding such dimensions and notes as would make the drawing useful as a descriptive illustration.

Immersion heaters offer one of the most economical means of heating liquids in tanks, kettles, metal barrels, etc. They are of substantial construction and high efficiency, utilizing the Calrod sheath wire. The screw-in type is easily installed, the only requirement being a hole with standard pipe thread in the container. Figure 686 shows a typical installation of a Calrod heater. In this unit an oil conducting medium is heated and in turn heats a second tank which may contain a heavy viscous liquid or other liquid that would carbonize easily. Tank 1 for liquid to be heated is 9" square by 6" deep, inside,

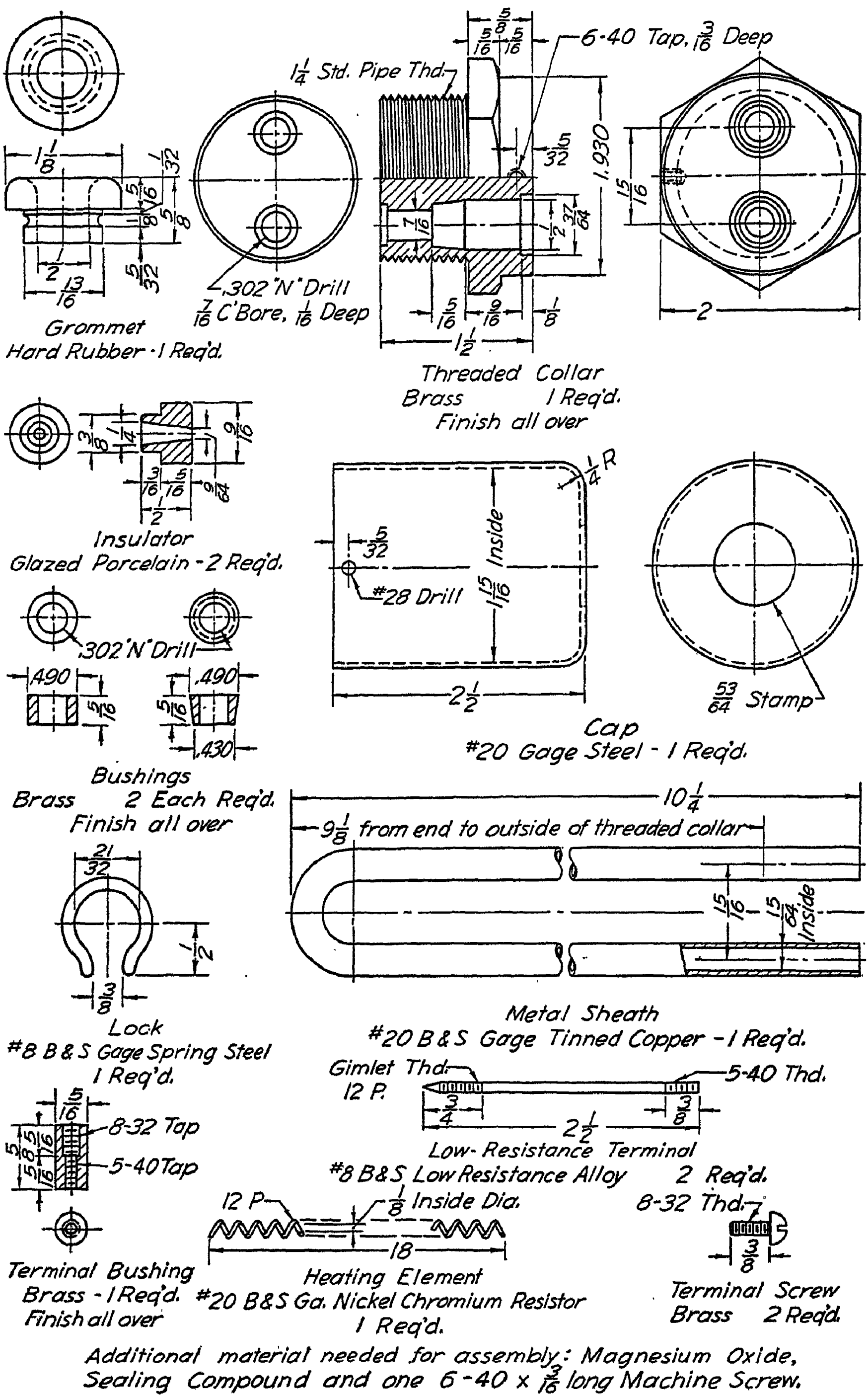


FIG. 685.—Details of immersion heater.

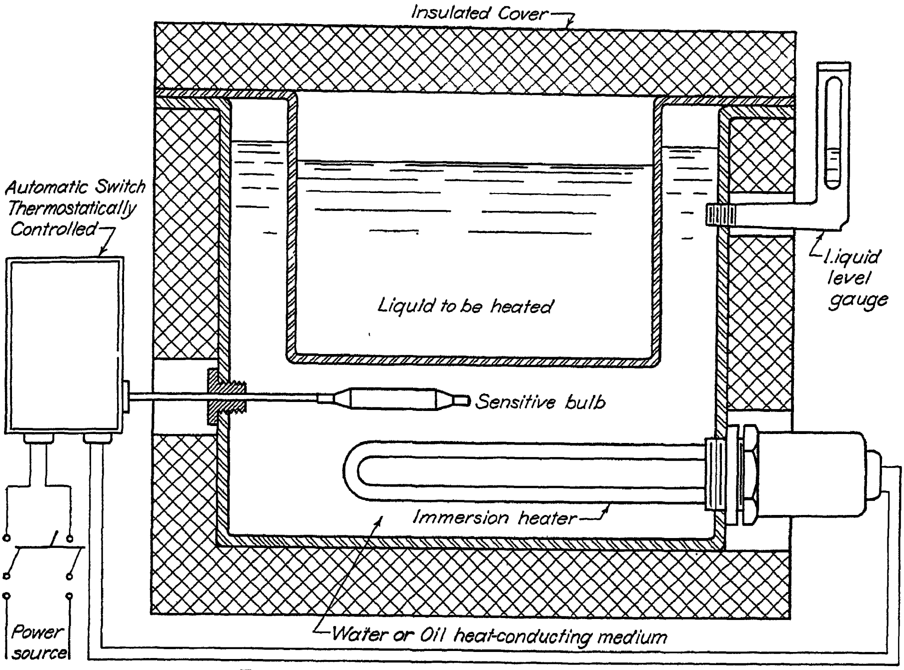


FIG. 686.—Installation of immersion heater.

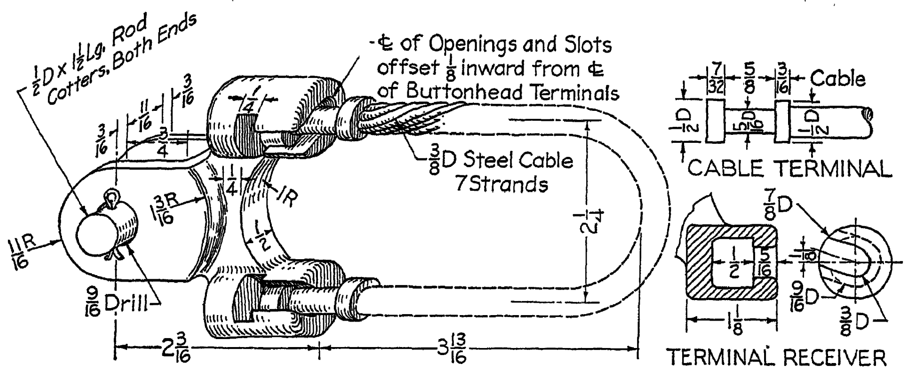


FIG. 687.—Insulator fitting.

and of No. 2 B & S gage sheet copper with a lip 3¾″ all around, measured from inside. Tank 2 for water or oil bath, 12″ square by 9″ deep inside and 0.2500-inch steel plate with a lip 2¼″ all around, measured from inside. The outer tank is covered on all sides, top and bottom, with insulating material.

118. Fig. 686. Make an assembly drawing in section showing tanks in position, with the heating unit installed in the tank wall. Equip the unit with a liquid-level gage for the conducting medium and with a sensitive bulb as part of a thermostat controlling a contactor in the 115-volt line. Include also a dropping resistor in the a-c line to the thermostat. Show the contactor and a fused line-switch to the 115-volt line.

119. Fig. 687. Make detail drawings of the insulator fitting. The buttonhead terminal openings in the body slope inward to prevent them from pulling out of the body when strain is applied.

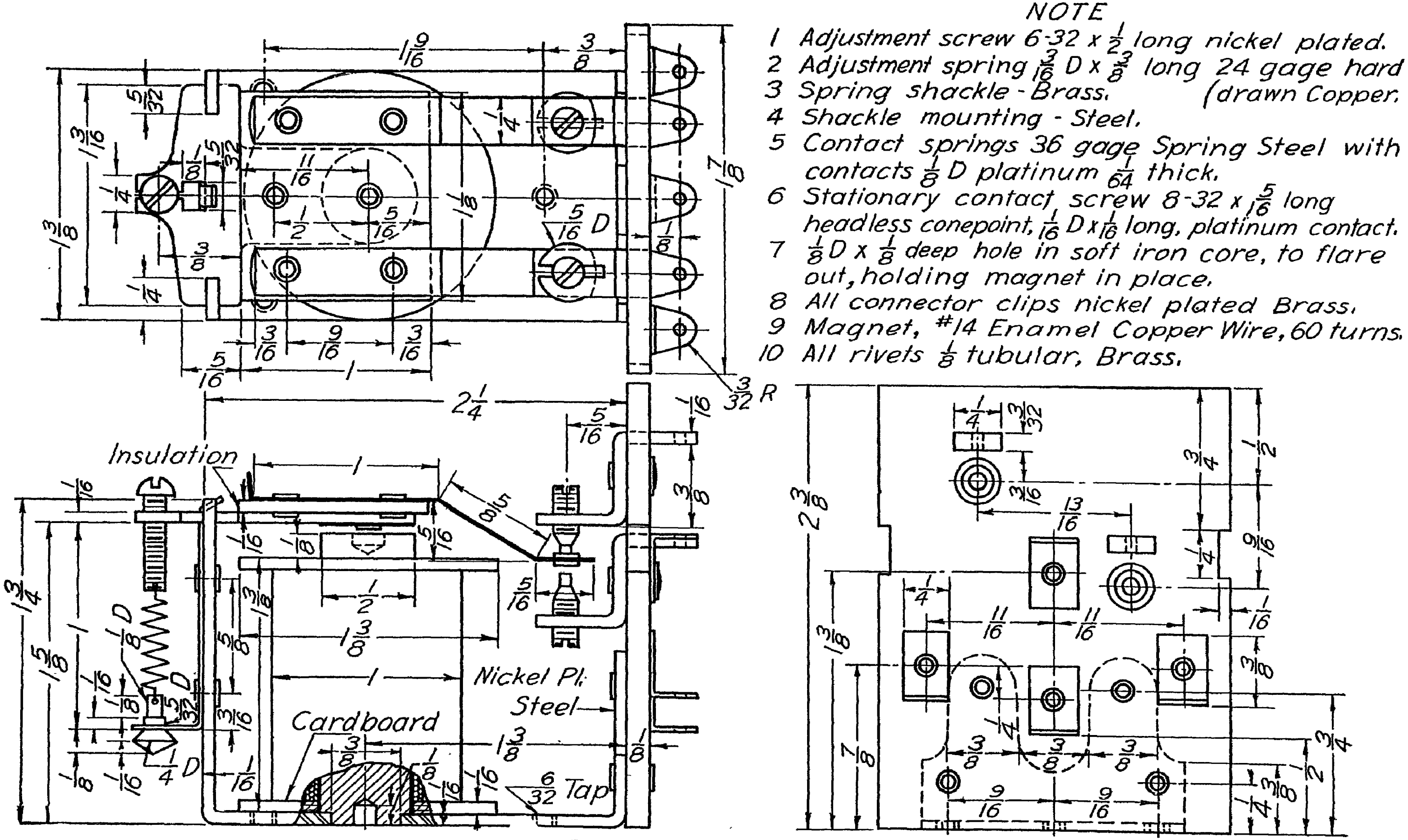


FIG. 688.—Relay assembly.

120. Make a diagrammatic sketch from information given in a catalogue of electrical control equipment for the installation of a thermostat bulb in a bearing retainer of a machine. Arrange so that the bulb will actuate a relay and disconnect power to the driving source if the bearing overheats.

121. Make a diagrammatic sketch from information given in a catalogue of electrical control equipment for the installation of an overcurrent relay in the supply line to electrical equipment. Arrange so that the relay will actuate the trip coil of a circuit breaker when the current reaches a dangerous value for continuous operation.

122. Fig. 920. Make outline plan drawings of the house, scale ¼″ = 1′-0″. Add the wiring plan, using standard wiring symbols. The current supplied is single phase, three wire, 110 volt, entering overhead at the rear.

123. Make a material list for Prob. 122. Use BX cable throughout.

124. Same as Prob. 122, but for one of the houses of Fig. 941 to 945.

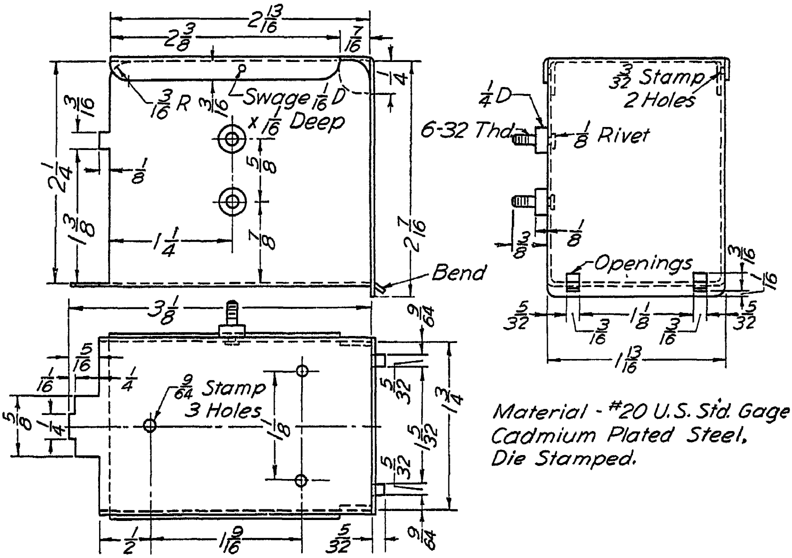


FIG. 689.—Case for relay.

125. Select a popular radio receiver circuit and make a complete wiring diagram, using symbols shown in the Appendix.

126. Fig. 688. Make detail working drawings of all parts of the relay. All metal parts are die-stamped; hence developed views can be used to advantage in showing these parts.

127. Fig. 689. Make a developed working drawing of the relay case. Add on the sheet a bill of material for the complete relay and case, and a drawing of the panel to show connections needed.

128. Fig. 690. Miniature switchboard. A miniature switchboard is used to control the larger main switchboard and equipment in a power station or substation. Draw a floor plan of a substation using three miniature switchboards each 24″ wide, 48″ deep and 90″ high and arranged in one unit so as to control 18 main switchboards. Show lighting, windows, doors, and any other features necessary on the floor plan, making the floor space adequate for inspection of the rear of the main switchboards. Building to be of reinforced concrete and brick fireproof construction.

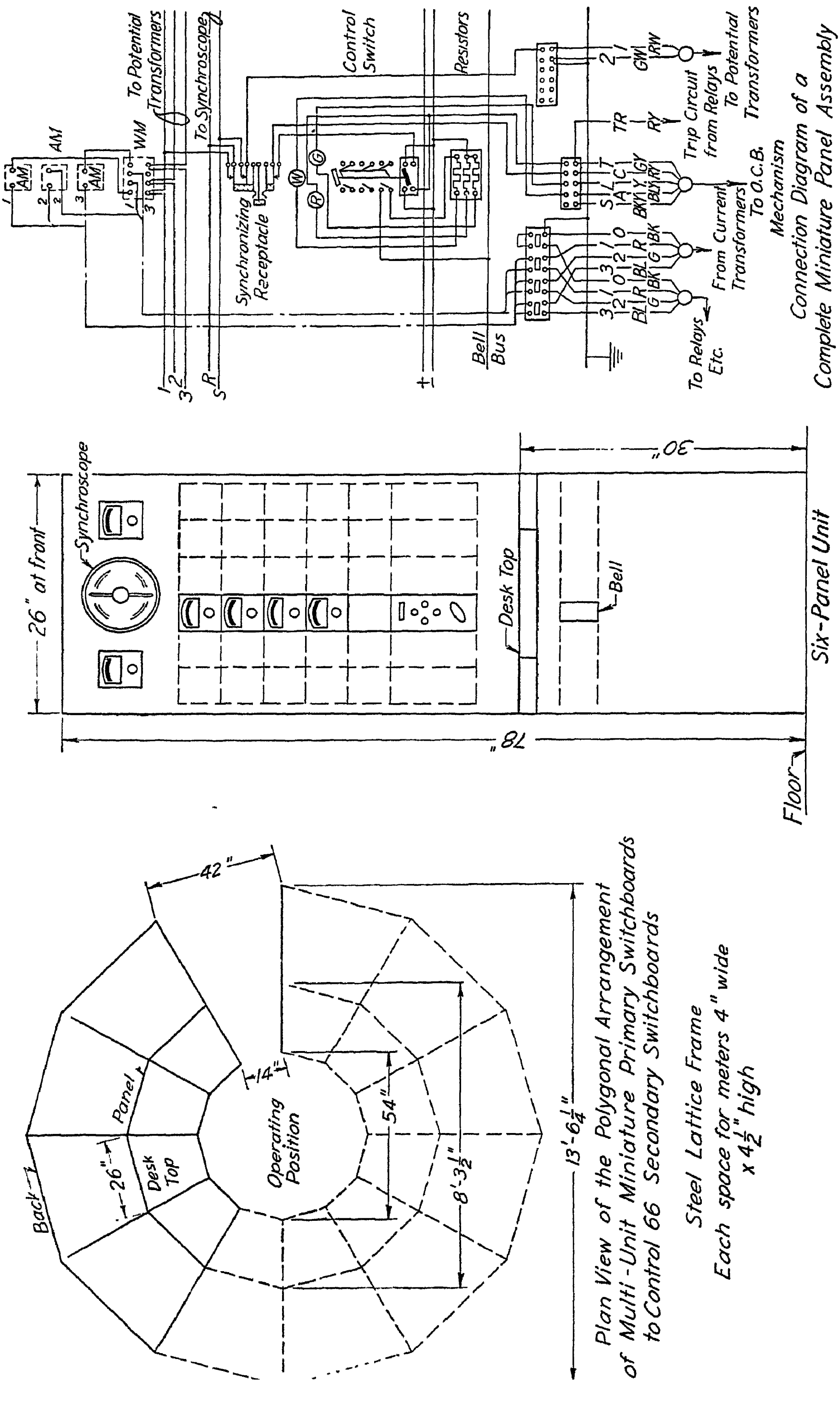


FIG. 690.—Miniature primary switchboard.

CHAPTER XV

WELDING DRAWINGS

270. The subject of welding is of particular interest to the draftsman for two reasons: first, welding is being used more and more extensively for permanent fastenings in places where formerly rivets or bolts were employed, and the draftsman must know not only what type of joint to use but also how to specify it with the standard code of symbols. Second, the method of designing and fabricating welded machine parts that have heretofore been made as castings or forgings is gaining rapidly in favor. A wide variety of parts such as machinery bases, frames and brackets are built up of standard steel shapes and plates joined by arc or oxyacetylene welding.

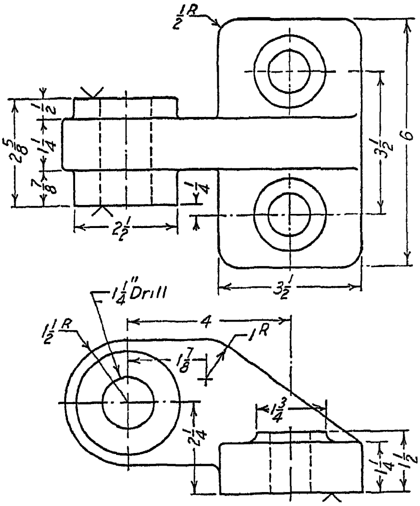


FIG. 691.—Detail drawing of casting.

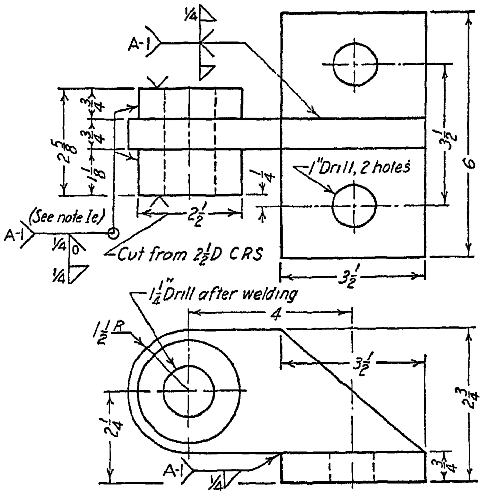


FIG. 692.—Detail drawing, welded construction.

Since steel is approximately six times as strong in tension as cast iron and two and one-half times as stiff, it is apparent that by using steel greater strength and rigidity may be secured with less weight of metal. Designing for welded steel construction requires ingenuity but is in reality simpler than designing complicated cast parts. The strength and weight of rolled steel shapes are standard, complete detailed information is readily available, and the computations for sizes of members are therefore greatly simplified.

As to the strength of welded connections, it is possible to make a welded joint stronger than the members joined.

271. Welding Drawings.—A welding drawing shows a unit or part made of several pieces of metal, with each welded joint described and specified. The first welding drawings carried a general note as, "to be welded throughout," or, "to be completely welded." A later system indicated the weld by a series of cross marks with an informative note either on the symbol or

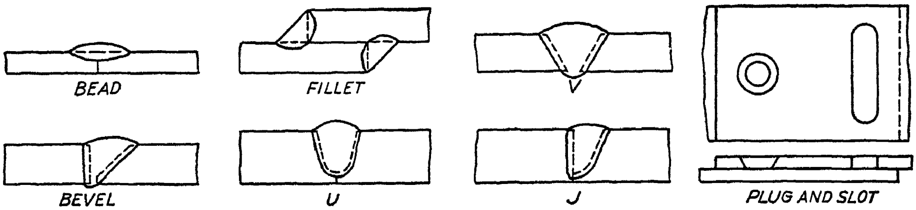


FIG. 693.—Fundamental welds.

elsewhere on the drawing. The American Welding Society in October, 1940, recommended its final draft of a complete system of specification by means of ideographic symbols, and the basic system has been adopted by the American Standards Association. Figure 691 shows the detail drawing of a part made of cast iron, and Fig. 692 shows a part identical in function but

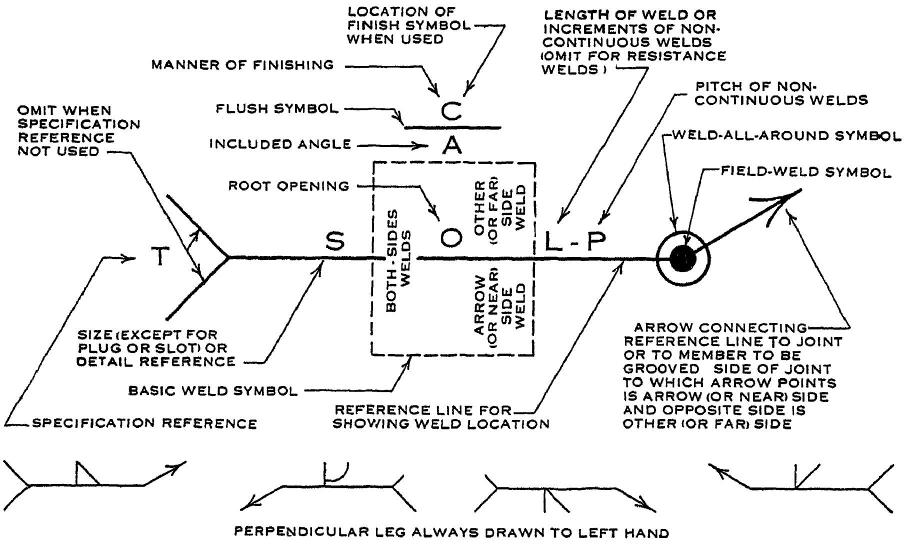


FIG. 694.—Basic form of the welding symbol.

made up by welding. A comparison of the two drawings shows the essential differences both in construction and in drawing technique. Note the absence of fillets and rounds in the welding drawing. Note also that the welded part uses pieces easily cut from standard stock.

272. Types of Welds.—Figure 693 shows in cross section the fundamental types of welds. For bead and fillet welds, the pieces are not prepared

by cutting, chipping or grinding before making the weld, and the essential difference in V-, bevel, U- and J-welds is in the preparation of the parts joined. Pairs of the fundamental welds such as double V, double bevel, etc., make a further variety. Almost any combination is possible for complicated connections.

273. The Basic Form of the Symbol.—Figure 694 shows the form of the welding symbol and gives the position of the various marks and dimensions. The information necessary to specify the weld, including all sizes of the weld

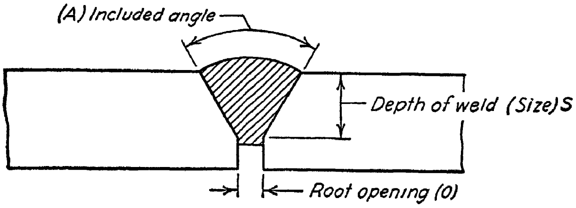


FIG. 695.—Weld sizes.

proper, is placed on the body of the leader as indicated. Figure 695 shows a typical weld in cross section, with the dimensions of root opening, depth of weld and included angle, which are the important sizes to specify.

The arrow points to the grooved member at a point near the weld, Fig. 696. The side of the weld pointed to is always called the arrow side (or near side). The tail of the arrow is used to hold a symbol only when specification of strength, type of rod, etc., are to be given.

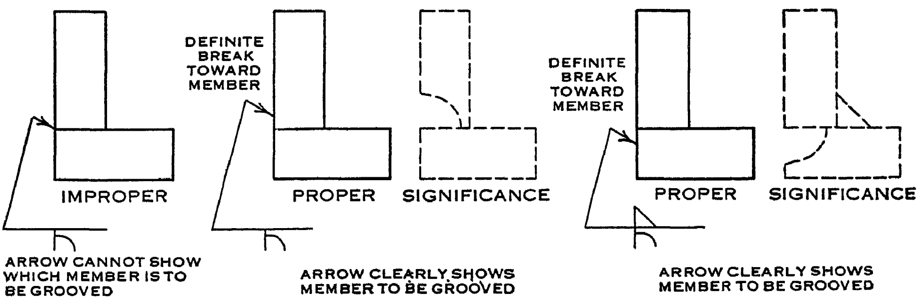


FIG. 696.—Placement of arrow.

Figure 697 illustrates the placement of the symbol and shows arrow sides and other sides of the weld on some fundamental types.

274. The Symbols.—Figure 698 shows arc and gas welding (fusion) symbols and illustrates their use. The individual basic symbols are placed on the basic form to describe any possible combination of welds for a complete joint. Every simple weld which is a part of the complete joint must be specified. The symbol describes a given weld in less space than would be required for dimensions and notes and requires much less drawing time.

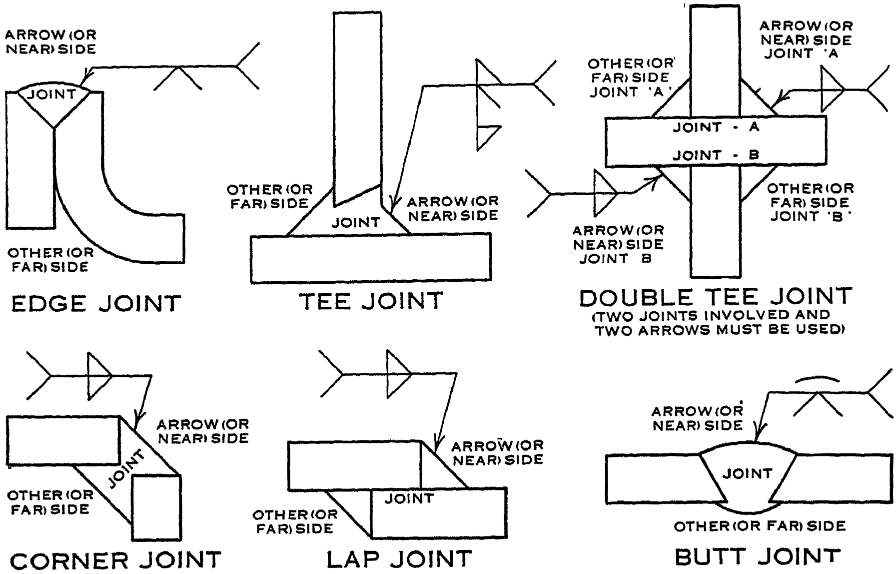
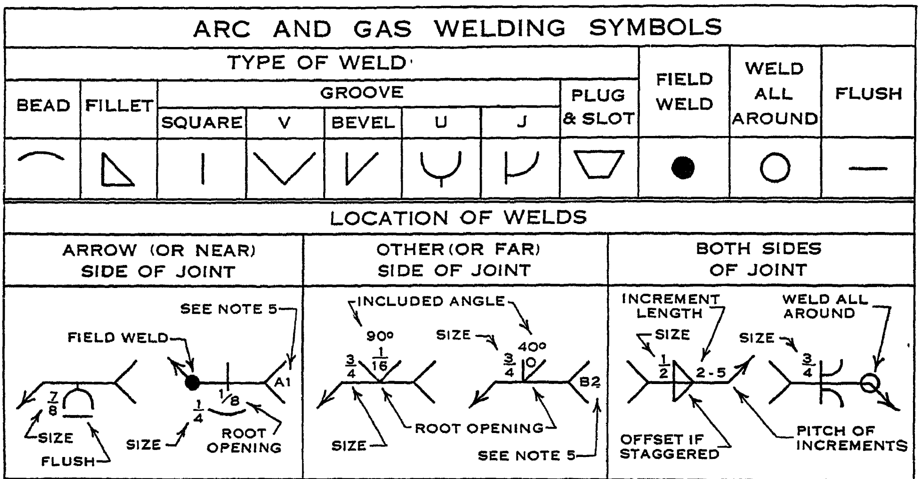


Fig. 697.—Arrow sides and other sides.



1 THE SIDE OF THE JOINT TO WHICH THE ARROW POINTS IS THE ARROW (OR NEAR SIDE)

2 BOTH-SIDES WELDS OF SAME TYPE ARE OF SAME SIZE UNLESS OTHERWISE SHOWN

3 SYMBOLS APPLY BETWEEN ABRUPT CHANGES IN DIRECTION OF JOINT OR AS DIMENSIONED (EXCEPT WHERE ALL AROUND SYMBOL IS USED)

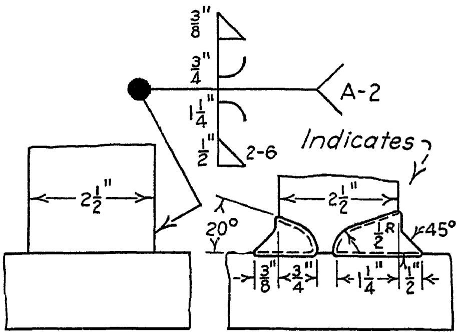
4 ALL WELDS ARE CONTINUOUS AND OF USER'S STANDARD PROPORTIONS, UNLESS OTHERWISE SHOWN

5 TAIL OF ARROW USED FOR SPECIFICATION REFERENCE (TAIL MAY BE OMITTED WHEN REFERENCE NOT USED)

6 DIMENSIONS OF WELD SIZES, INCREMENT LENGTHS AND SPACINGS IN INCHES

Fig. 698.—American Standard fusion welding symbols.

A comparison is made in Fig. 699 between the information given by the symbol, the joint dimensioned, and a complete note. Study each part of the symbol carefully in connection with the dimensioned sketch and the note.



Interpretation of Symbol:

Double-fillet-welded, partially grooved, double-J, tee joint with incomplete penetration. (Type of joint shown by drawing.) Grooves of standard proportions (which are ½ in. *R*, 20° included angle, edges in contact before welding), ¾ in. deep for other (or far) side weld and 1¼ in. deep for arrow (or near) side weld. ⅜ in. continuous other (or far) side fillet weld and ½-in. intermittent arrow (or near) side fillet weld with increments 2 in. long, spaced 6 in. center to center. All fillets standard 45° fillets. All welding done in field in accordance with welding specification number A2 (which requires that weld be made by manual d.c. shielded metal-arc process, using high-grade, covered, mild steel electrode; that root be unchipped and welds unpeened but that joint be preheated before welding).

FIG. 699.—A comparison.

275. Classification of Welded Joints.—Joints may be classified by the method of assembly of the parts, and further differentiated by the way in which the parts are prepared for welding. Figure 700 classifies some typical joints and gives the welding symbols for each.

276. Use of the Symbols.—The following instructions should be followed for placement and form of the symbols. Some practices to avoid are also given.

INSTRUCTIONS FOR USE OF WELDING SYMBOLS

I. General.

a. Do not use the word "weld" as a symbol on drawings.

b. Symbols may or may not be made freehand as desired.

c. Inch, degree and pound marks may or may not be used as desired.

d. The symbol may be used without specification references or tails to designate the most commonly used specification when the following note appears on the drawing:

"Unless otherwise designated, all welds to be made in accordance with welding specification No. —."

e. When specification references are used, place in tail, thus:

f. Symbols apply between abrupt changes in direction of joint or to extent of hatching or dimension lines (except where all-around symbol is used). See IV *d* and *e*.

g. Faces of welds assumed to have user's standard contours unless otherwise indicated.

h. Faces of welds assumed not to be finished other than cleaned unless otherwise indicated.

i. All except plug, spot and projection welds assumed continuous unless otherwise indicated.

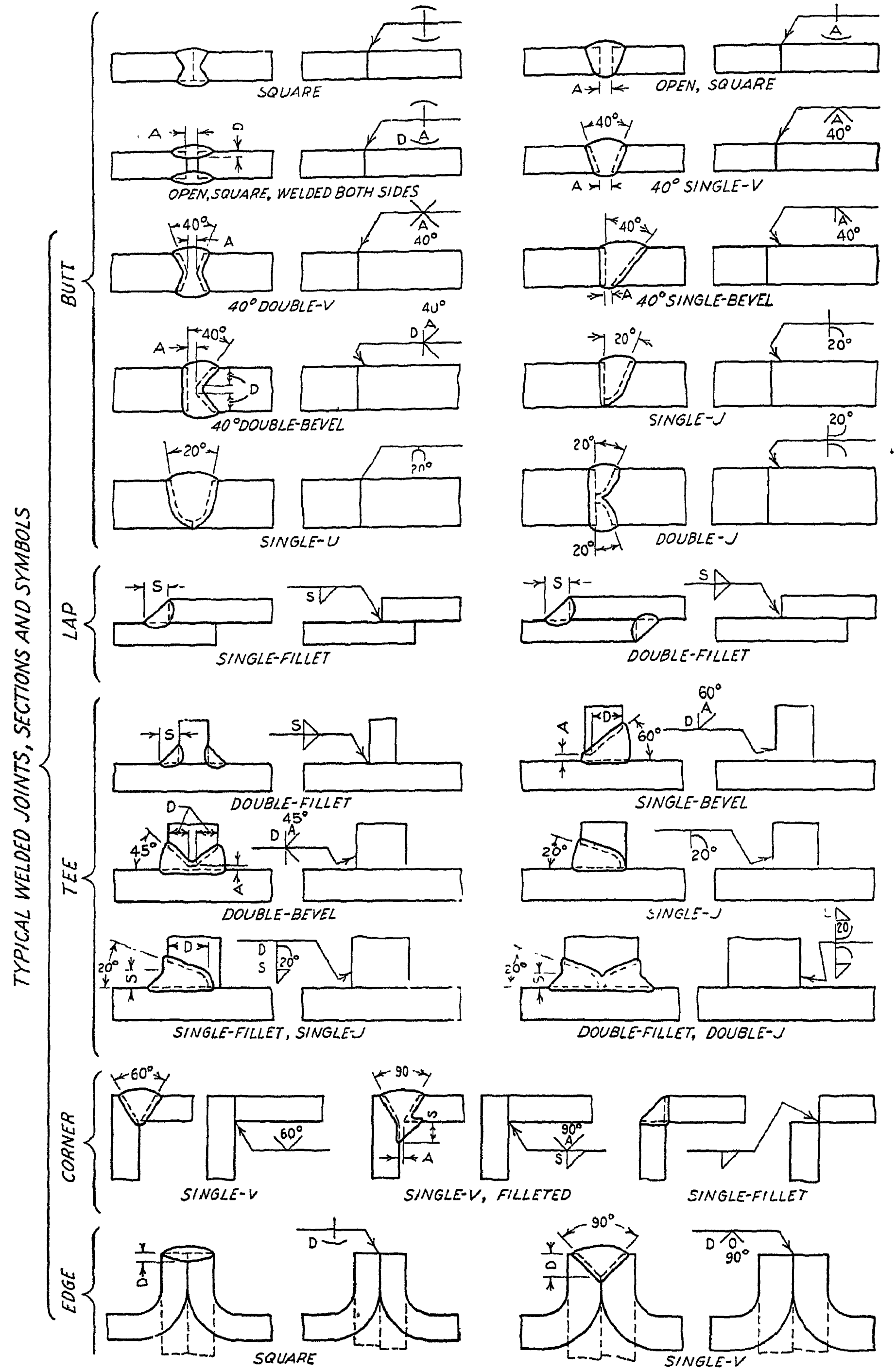
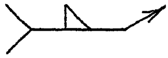


Fig. 700.—Classification of welded joints.

II. Arc and gas welds.

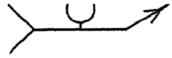
1. General.

a. Do not put symbol directly on lines of drawing; place symbol on reference line and connect latter to joint with arrow, thus:



b. For welds on arrow (or near) side of joint show symbol on near side of reference lines, face toward reader, thus:

c. For welds on other (or far) side show symbol on far side of reference line, face away from reader, thus:

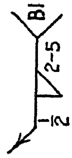


d. For welds on both sides of joint show symbols on both sides of reference line, faces toward and away from reader, thus:

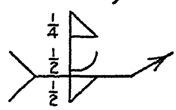
e. Where the part shown is but one of a series of practically identical parts (see the boss in Fig. 692), the applicability of the symbols to the concealed parts shall be in accordance with the user's standard drawing practices with regard to dimensioning and part-numbering such parts.

f. Where one member only is to be grooved, show arrow pointing unmistakably to that member. See Fig. 696.

g. Read symbols from bottom and right-hand side of drawing in the usual manner and place numerical data on vertical reference lines so that reader will be properly oriented, thus:

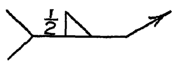


h. Show symbol for each weld in joints composed of more than one weld, thus:
(Give numerical data in proper location with regard to each symbol.)

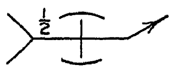


i. In complicated joints requiring large compound symbols two separate sets of symbols may be used if desired.

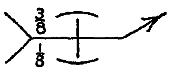
j. Show dimensions of weld on same side of reference line as symbol, thus:



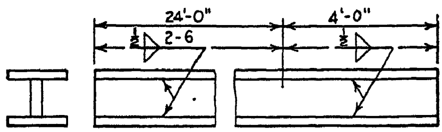
k. Show dimensions of one weld only when welds on both sides of the joint are of the same type and size, thus: (If size of undimensioned fillets is governed by a note on the drawing, all weld sizes different from that covered in the note must be given.)



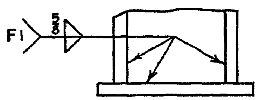
l. Show dimensions for welds on both sides of the joint, when the arrow-side and other-side welds are different, thus:



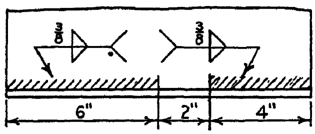
m. Indicate specific lengths of welds in conjunction with dimension lines, thus:



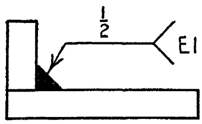
n. Show the welding between abrupt changes in the direction of the weld thus (except when all-around symbol is used; see IV *d* and *c*):



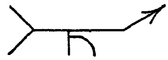
o. When it is desired to show extent of welds by hatching, use one type of hatching with definite end lines, thus:



p. If actual outlines of welds are drawn in section or end elevation, basic symbol is not necessary to show type and location; size or other numerical details only need to be given, thus:

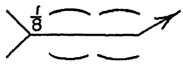


q. Show fillet, bevel- and J-groove weld symbols with perpendicular leg always to the left hand, thus:



2. Bead welds.

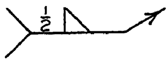
a. Show bead welds used in building up surfaces (size is minimum height of pad) thus:

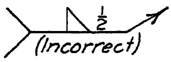


b. When a small but no specific minimum height of pad is desired, show thus:

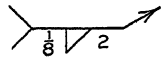
3. Fillet welds.

a. Show size of fillet weld to the left of the perpendicular leg, thus:

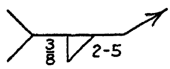




b. Show specific length of fillet weld or increment after size so that data read from left to right, thus:

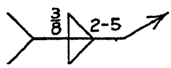


c. Show center-to-center pitch of increments of intermittent fillet welds after increment length so that data read from left to right, thus:

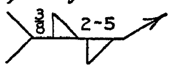


d. Use separate symbol for each weld when intermittent and continuous fillet welds are used in combination.

e. Show two intermittent fillet welds with increments opposite each other (chain) thus:

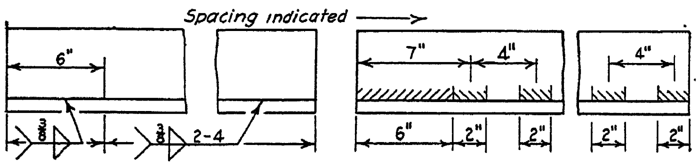


f. Show two intermittent fillet welds with increments not opposite each other (staggered) thus:



g. Measure pitch of intermittent fillet welds between centers of increments on one side of member.

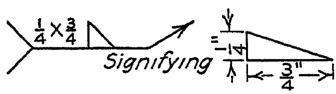
h. Increments and not spaces assumed to be at ends of all intermittent welds and over-all length dimensions govern to ends of those increments, thus:



i. Faces of fillet welds assumed to be at 45° from legs unless otherwise indicated.

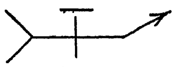
j. When the face of a fillet weld is to be at any other angle than 45°, two dimensions are necessary to designate fully the size of the weld. Place these dimensions in parentheses so that the two-dimensional size data will be a single entity and will not be confused with length of increment and spacing data.

Show on drawings positions of legs relative to members.



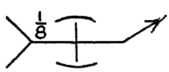
4. Groove welds.

a. Show side from which square-groove weld is made by bead or flush symbols, thus (see III, 4*a*; IV, *h*; and IV, *j* and *k*):

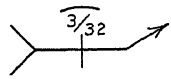


b. Total penetration of square-groove welds assumed to be complete unless otherwise indicated.

c. Show size of square-groove welds (depth of penetration) when penetration is less than complete, thus:

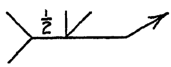


d. Show root opening of open, square-groove welds inside symbol, thus:



e. Total depth of V- and bevel grooves before welding assumed to be equal to thickness of member unless otherwise indicated.

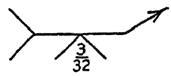
f. Show size of V- and bevel-groove welds (depth of single groove before welding) when grooving is less than complete, thus:



g. Total depth of penetration of V- and bevel-groove welds assumed complete, unless, with usual welding processes, depth of grooving is such that complete penetration is not possible, when depth of penetration is assumed to be depth of groove plus normal penetration. When using welding processes giving abnormal penetration, give information on latter by detail or note. See IV, *j*.

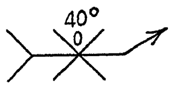
h. Root opening of V- and bevel-groove welds assumed to be user's standard unless otherwise indicated.

i. Show root openings of V- and bevel-groove welds when not user's standard, inside symbol, thus:



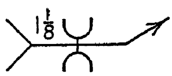
j. Included angle of V- and bevel-groove welds assumed to be user's standard unless otherwise indicated.

k. Show included angle of V- and bevel-groove welds when not user's standard inside symbol, thus:

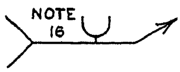


l. Proportions of U- and J-groove welds assumed to be user's standard unless otherwise indicated.

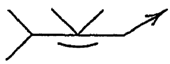
m. Show size of U- and J-groove welds (depth of single groove before welding) having user's standard proportions but incomplete penetration, thus:



n. When proportions of U- and J-groove welds are not user's standard, show weld by detail or reference drawing and use reference symbol, thus (see IV, *o*):

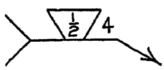


o. Show welding done from root side of single-groove welds with bead weld symbol, thus:



5. Plug and slot welds.

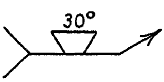
a. Show size of plug and slot welds (root opening and root length), thus:



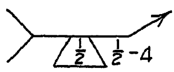
(Root opening equals root length for plug welds.)

b. Included angle of bevel of plug and slot welds assumed to be user's standard unless otherwise indicated.

c. Show included angle of bevel of plug and slot welds when not user's standard, thus:



d. Show pitch of plug and slot welds in row, thus:



e. Show fillet-welded holes and slots with proper fillet-weld symbols and not with plug-weld symbols.

III. Resistance welds.

1. General.

a. Center resistance-welding symbols for spot and seam welds on reference line because these symbols have no arrow-side or other-side (near- and far-side)

significance (see Fig. 701 and also refer to IV *m*), but do not center projection welding symbols, because the latter have such significance.

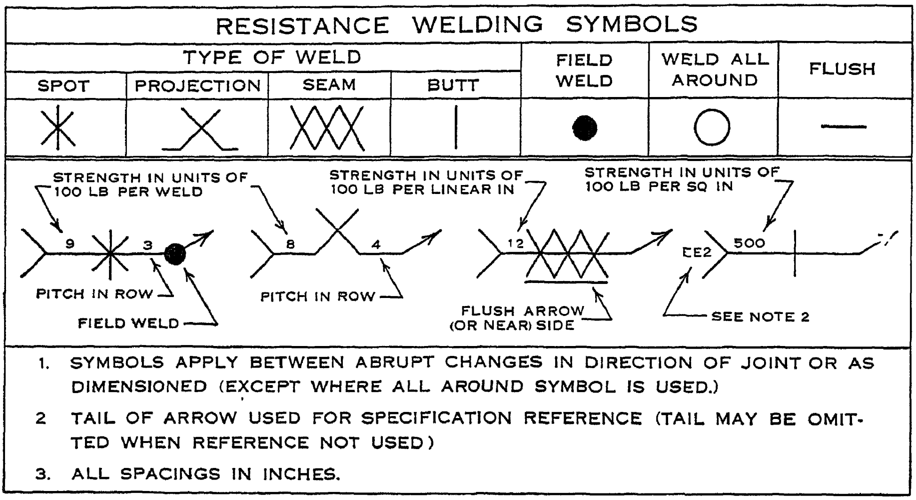
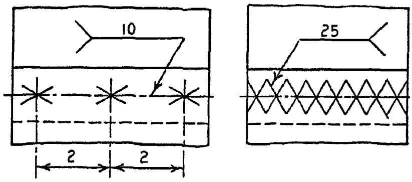


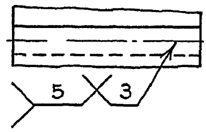
FIG. 701.—American Standard resistance welding symbols.

b. Designate resistance welds by strength rather than size (because of impracticability of determining latter).

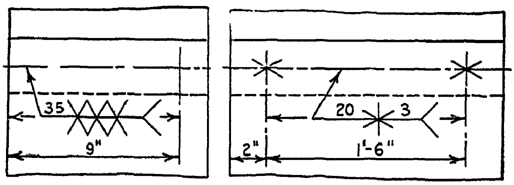
c. Spot- and seam-weld symbols may be used directly on drawings, thus; but projection-weld symbols should not:



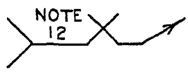
d. When not used on lines of drawing, connect reference line to center line of weld or rows of welds with arrow, thus:



e. Show welds of extent less than between abrupt changes in direction of joint, thus:

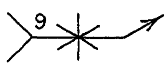


f. When tension, impact, fatigue or other properties are required, use reference symbol, thus (see IV, *o*):

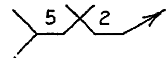


2. Spot and projection welds.

a. Show strength of spot and projection welds in single shear in units of 100 pounds per weld, thus:

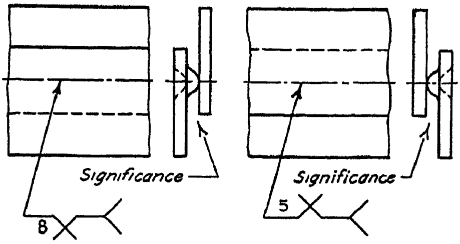


b. Show strength and center-to-center spacing of spot and projection welds in row, thus:

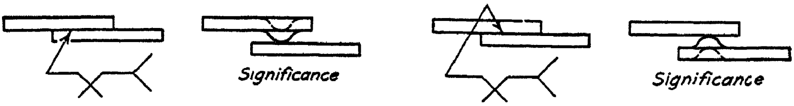


c. Proportions of projections assumed given on drawing.

d. In a projection-welded joint parallel, or nearly so, to the plane of the paper, show whether the arrow (or near) side or other (or far) side member is to be embossed by placing the projection-weld symbol on the arrow (or near) or the other (or far) side of the reference line, thus:



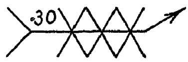
e. In a projection-welded joint shown in section or end view, show which member is to be embossed by pointing arrow to that member, thus:



3. Seam welds.

a. Seam welds assumed to be of overlapping or tangent spots. If any spacing exists between spots, welds are considered to be a series of spot welds, and spot symbol should be used.

b. Show shear strength of seam welds in units of 100 pounds per linear inch, thus:

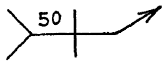


4. Butt welds.

a. Show resistance butt welds without bead-weld symbol, signifying that weld is not made from any side, but all at once, thus (see II, 4a):

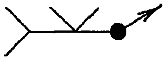
b. Resistance butt welds assumed to be equal to strength of base metal in tension unless otherwise indicated.

c. When a different strength is desired, show strength of butt welds in tension in units of 100 pounds per square inch, thus:



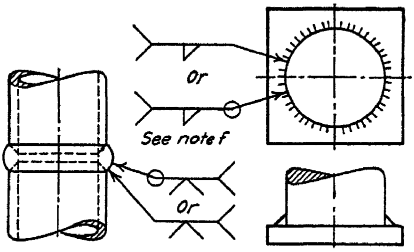
IV. Supplementary symbols.

a. Show "field" welds (any weld not made in shop), thus:

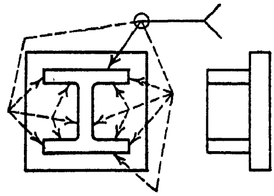


b. Show "all-around" welds, weld encircling joint (or joints) in so far as is possible, thus:

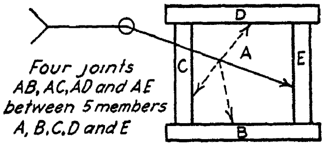
c. When the weld encircles the joint but there is no abrupt change in the direction of the joint or parts of the joint (changes in the direction of rolled structural sections are considered abrupt even though there are fillets in the corners), the all-around symbol may or may not be used as desired, thus:



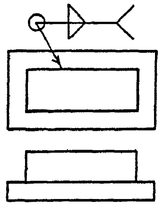
d. The all-around symbol extends control of the welding symbol beyond abrupt changes in the direction of one joint, or parts of one joint, to encirclement of the complete joint in so far as is possible, thus:



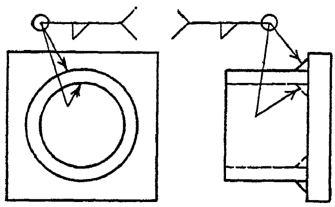
e. The all-around symbol extends the control of the welding symbol not only beyond abrupt changes in the direction of one joint, but to two or more joints to the encirclement of the joints in so far as is possible, thus:



f. When the use of an arrow-side or other-side symbol, together with an all-around symbol, results in a weld on both sides of the joint as a whole, it is advisable to use the both-sides symbol, thus, even though a one-side symbol may be strictly correct (see (*g*) below):



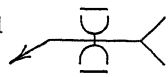
g. When the member involved is hollow or annular and there is more than one encircling weld, and there is likelihood of confusion existing as to whether or not a both-sides symbol would refer to a part of the joint or to the joint as a whole, show each encircling weld with a separate arrow, thus:



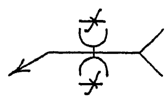
h. The locations of the flush and finish symbols have the usual arrow- and other- (near- and far-) side significance and govern only the sides on which they are shown.

i. Finish marks govern faces of welds only and not base metal either before or after welding.

j. Show arc and gas welds made flush without recourse to any kind of finishing, thus:



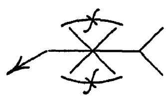
k. Show arc and gas welds made flush by mechanical means with both flush and user's standard finish symbols, thus:



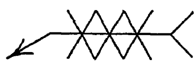
The following letters are suggested for indicating finishing processes:

C—Chip G—Grind M—Machine

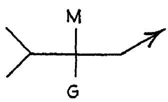
l. Show finishing on face of arc and gas welds, which need not be flush, with user's standard finish symbols on bead symbol, thus:



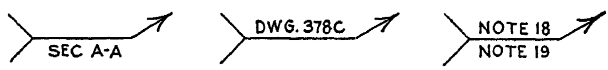
m. Show spot, seam or projection welds made practically flush (with minimum indentation), thus:



n. Show resistance butt welds, finished by mechanical means, without flush symbol, thus:



o. Show special welds not covered by any of the above symbols by a detailed section or reference drawing, or give any supplementary information by means of a note and refer weld to section, drawing, or note by a reference symbol. Reference symbol has usual location significance, thus:



PROBLEMS

The draftsman should be so thoroughly familiar with the welding symbols that he can write and read them without hesitation. Problems 1 and 2 give practice in reading, 3 and 4 in writing. Problems 5 to 10 give practice in the use of the symbols on working drawings.

1, 2. Figs. 702, 703. Make full-size cross-sectional sketches (similar to Figs. 704 and 705) of the joints indicated. Dimension each sketch.

3, 4. Figs. 704, 705. Sketch members and show welding symbol for each complete joint. Estimate weld size from plate thickness.

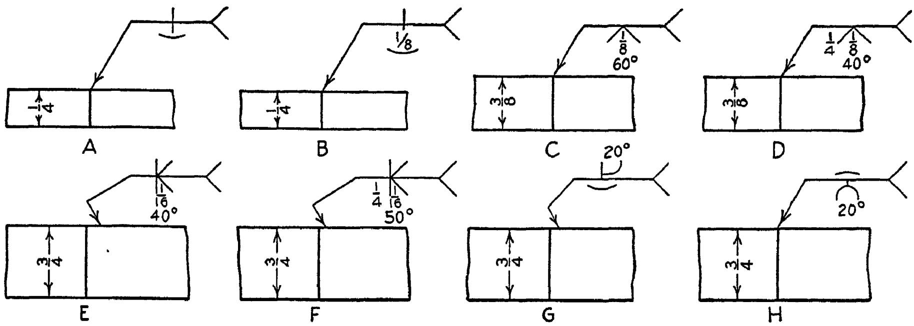


FIG. 702.—Butt joints.

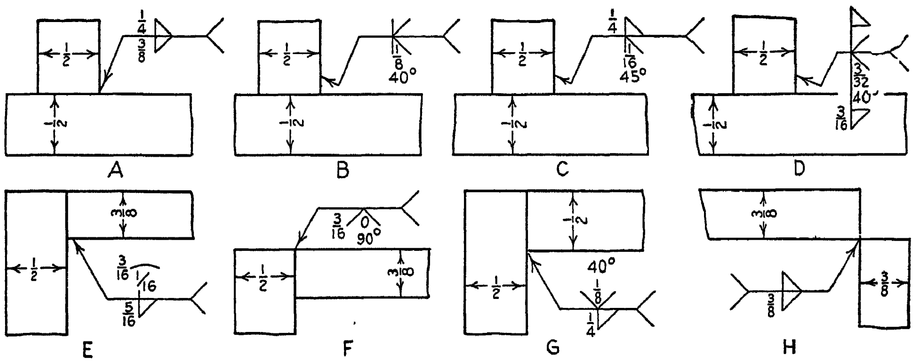


FIG. 703.—Tee and corner joints.

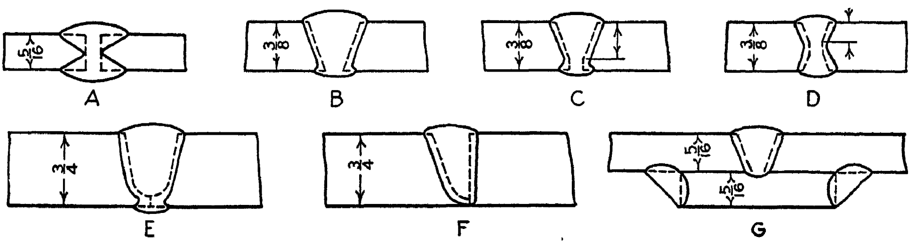


FIG. 704.—Butt joints.

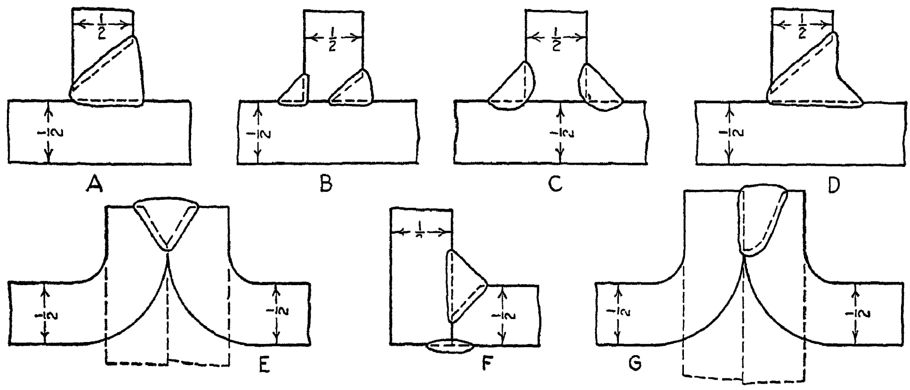


FIG. 705.—Tee, corner and edge joints.

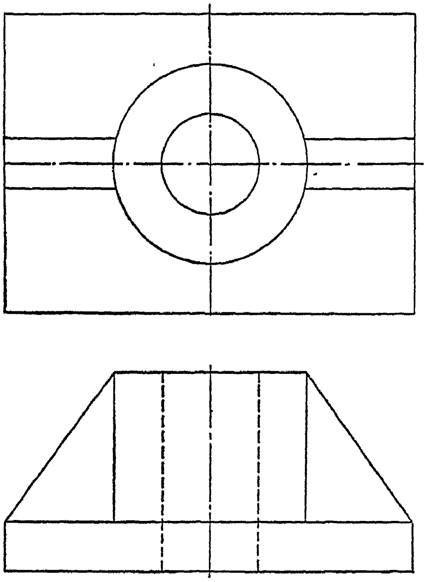


FIG. 706.—Base.

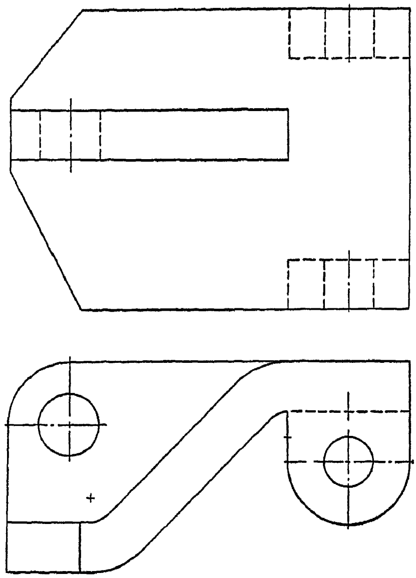


FIG. 707.—Hinge clip.

5, 6. Figs. 706, 707. Make complete welding drawing for each object. These problems are printed quarter size. Draw full size by scaling or transferring with dividers.

7, 8, 9, 10. Figs. 307, 308, 592, 600. Redesign for welded construction. Simplify so that the pieces used to make up the complete shape may be cut from standard stock.

CHAPTER XVI

GEARS AND CAMS

277. Gears.—The theory of gearing belongs to the study of mechanism. but the representation and specification of gears are of such common occurrence that the proportions and nomenclature should be familiar to the young engineer.

Briefly, gears are a substitute for rolling cylinders and cones, designed to ensure positive motion. There are numerous kinds of gears, of which the most common forms are *spur gears* for transmitting power from one shaft to another parallel shaft, and *bevel gears* for two shafts whose axes intersect, usually at right angles. When one gear of a pair is much smaller than the other it is called a "pinion."

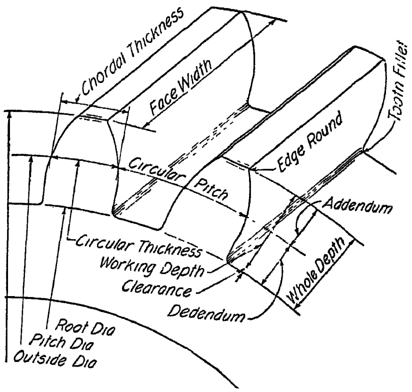


FIG. 708.—Nomenclature.

Some of the terms in the American Standard nomenclature of gearing are given in Fig. 708. In the calculations concerning gears the following standardized terms and abbreviations are used:

N = number of teeth = $DP \times PD$.

DP = diametral pitch = number of teeth in the gear for each inch of pitch diameter = N/PD.

PD = diameter of pitch circle = N/DP.

CP = circular pitch = the distance on the circumference of the pitch circle between corresponding points of adjacent teeth = $\pi PD/N = \pi/DP$.

CTh = circular thickness = the thickness of the tooth on the pitch circle = $CP/2$.

CT = chordal thickness = length of the chord subtended by the circular thickness arc = $PD \sin (90/N)$.

A = addendum = radial distance between the pitch circle and the top of the teeth = constant/DP (= for standard involute teeth $1/DP$).

D = dedendum = radial distance between the pitch circle and the bottom of the tooth space = constant/DP (= for standard involute teeth $1.157/DP$).

C = clearance = radial distance between the top of a tooth and the bottom of the mating tooth space = constant/DP (= for standard involute teeth $0.157/DP$).

WD = whole depth = radial distance between outside circle and root circle = $A + D$.

WDe = working depth = greatest depth to which a tooth of one gear extends into the tooth space of a mating gear = $2A$.

OD = outside diameter = the diameter of the greatest circle which contains the tops of the teeth $= PD + 2A$.
RD = root diameter = the diameter of the root circle $= PD - 2D$.
FW = face width = width of pitch surface.
ER = edge round = radius of the circumferential edge of a gear tooth (to break the corner)
TFi = tooth fillet = curved line joining the tooth flank and the bottom of the tooth space.

The necessary information concerning a gear may be found by counting the number of teeth and measuring the outside diameter.

Example: Given N and OD. To find DP.

$$OD = PD + 2A$$

Substitute in terms of DP,

$$OD = \frac{N}{DP} + \frac{2}{DP}$$

Then

$$OD = \frac{N + 2}{DP}$$

and

$$DP = \frac{N + 2}{OD}$$

In a similar way any required dimensions may be found by the solution of the proper equation.

In working drawings of gears and toothed wheels not all the teeth are drawn. For cast gears the pitch circle, outside circle, root circle and the full-sized outline of one tooth are drawn. For cut gears the blank is drawn and a note added concerning the number of teeth and pitch.

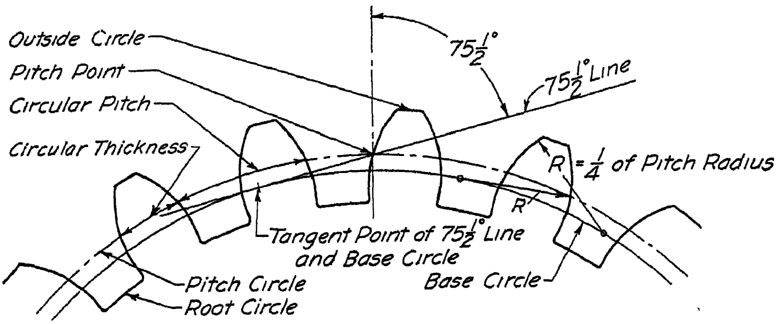


FIG. 709.—To draw an involute spur gear, approximate method.

278. To Draw a Spur Gear.—Fig. 709. To draw the teeth of a standard involute-toothed spur gear by an approximate circle-arc method, lay off the pitch circle, root circle and outside circle. Start with the pitch point and divide the pitch circle into distances equal to the circular thickness. Through the pitch point draw a line of $75\frac{1}{2}°$ with the center line (for convenience the draftsman uses 75°). Draw the base circle tangent to the 75°

line. With compasses set to a radius equal to one-fourth the radius of the pitch circle, describe arcs through the division points on the pitch circle, keeping the needle point on the base circle. Darken the arcs for the tops of the teeth and bottoms of the spaces, and add the tooth fillets. For 16 or

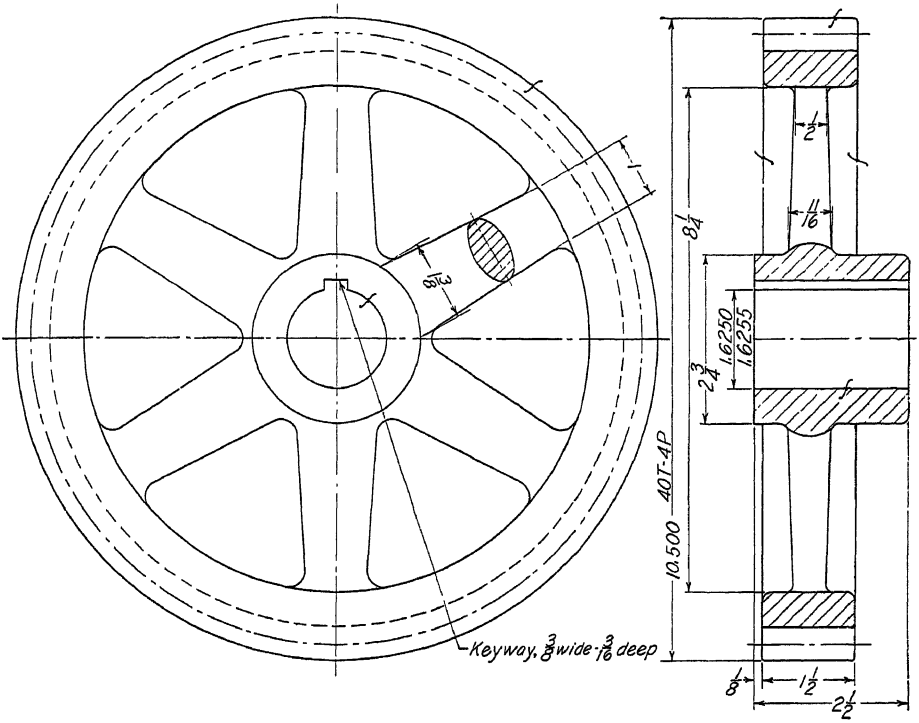


FIG. 710.—Working drawing of a spur gear.

fewer teeth the radius value of one-fourth the pitch radius must be increased to suit, in order to avoid the appearance of excessive undercut. For stub teeth the $75\frac{1}{2}°$ line is changed to 70°.

This method of drawing gear teeth is useful on display drawings. On working drawings the teeth are not drawn but are indicated as in Fig. 710.

279. To Draw a Rack.—Fig. 711. To draw the teeth of a standard involute rack by an approximate method, draw the pitch line and lay off the addendum and dedendum distances. Divide the pitch line into spaces equal to the circular thickness of the mating gear.

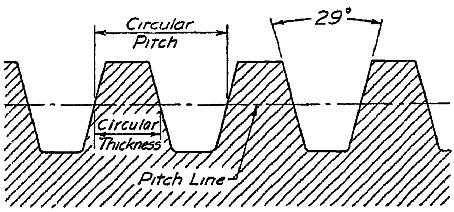


FIG. 711.—Involute rack.

Through these points of division draw the tooth faces at $14\frac{1}{2}°$ (15° is used by draftsmen). Draw tops and bottoms and add the tooth fillets. For stub teeth use 20° instead of $14\frac{1}{2}°$. Specifications of rack teeth (to

be given on a detail drawing) are: linear pitch (equal to circular pitch of the mating gear), number of teeth, diametral pitch, whole depth.

280. To Draw a Bevel Gear.—Fig. 712. To draw the teeth of an involute-toothed bevel gear by an approximate method (the Tredgold method). Draw the center lines, intersecting at *O*. Across the center lines lay off the pitch diameters and project them parallel to the center lines until the projectors intersect at the pitch point *P*. From the pitch point, draw the pitch-circle diameters for each gear and from their extremities the "pitch cones" to the vertex or "cone center" *O*. Lay off the addendum and

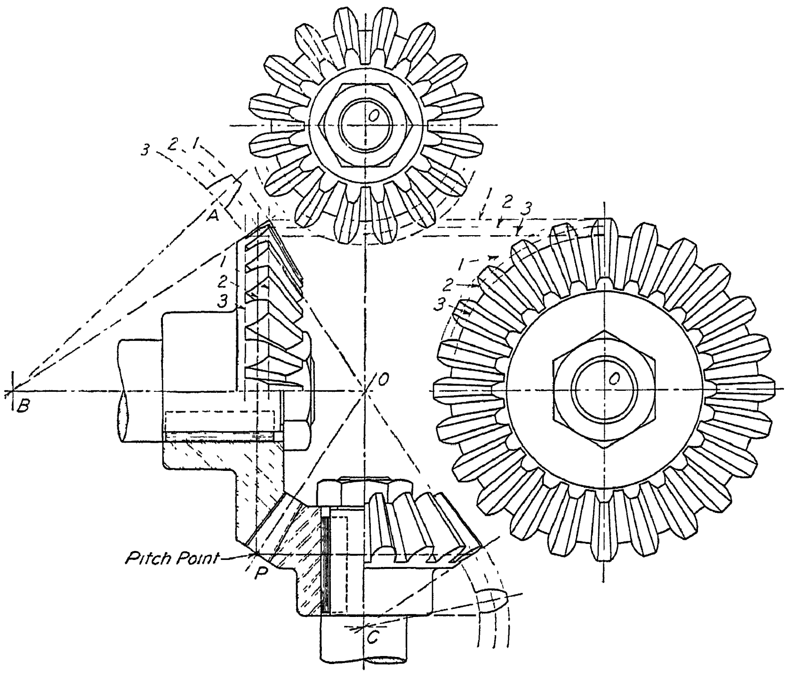


Fig. 712.—To draw involute bevel gears, approximate method.

dedendum distances for each gear on lines through the pitch points perpendicular to the cone elements. Extend one of these normals for each gear to intersect the axis, as at *B* and *C*, making the "back cones." With *B* as center, swing arcs 1, 2 and 3 for the top, pitch line and bottom, respectively, of a developed tooth. On a radial center line *AB*, draw a tooth, by the method of Fig. 709. Start the plan view of the gear by projecting points 1, 2 and 3 across to its vertical center line and drawing circles through the points. Lay off the radial center lines for each tooth. With dividers take the circular thickness distances from *A* and transfer them to each tooth. This will give three points on each side of each tooth through which a circle arc, found by trial, will pass, giving the foreshortened contour of the large end of the teeth in this view. From this point the drawing becomes a

problem in projection drawing. Note that in every view the lines converge at the cone center O, and that by finding three points on the contour of each tooth, circle arcs can be found by trial which will be sufficiently close approximations to give the desired effect.

This method is used for finished display drawings. Working drawings for cut bevel gears are drawn without tooth outlines, as shown in Fig. 713. For a cast gear the tooth outline must be given for the patternmaker.

281. Cams.—A cam is a machine element with surface or groove formed to produce special or irregular motion in a second part, called a "follower." The shape of the cam is dependent upon the motion required and the type of

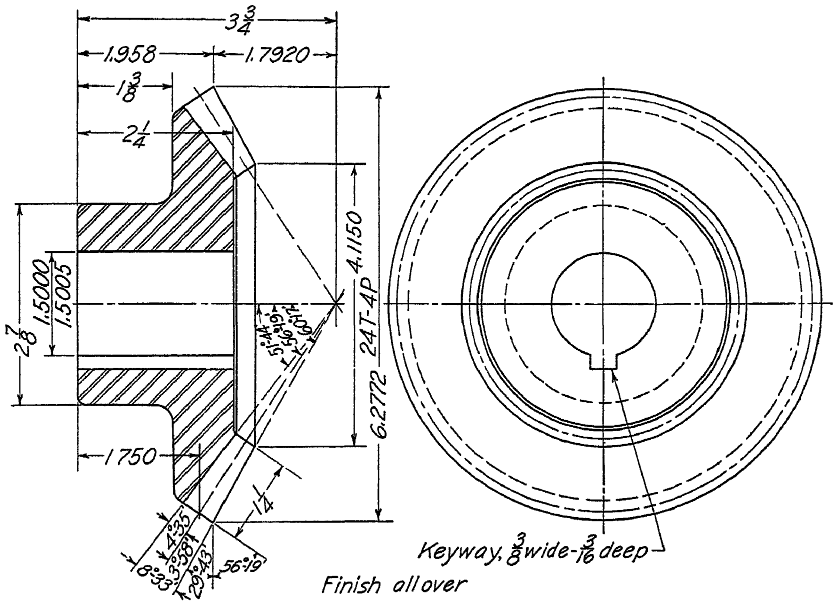


Fig. 713.—Working drawing of a bevel gear.

follower that is used. The type of cam is dictated by the required relationship of the parts, and the motions of both.

282. Types of Cams.—The direction of motion of the follower with respect to the cam axis determines two general types, as follows: (1) radial or disk cams, in which the follower moves in a direction perpendicular to the cam axis, and (2) cylindrical or end cams, in which the follower moves parallel to the cam axis. Figure 714 shows at A a *radial cam*, with a roller follower held against the cam by gravity or by a spring. As the cam revolves the follower is raised and lowered. Followers are also made with pointed ends and with flat ends. B shows a *face cam*, with a roller follower at the end of an arm or link, the follower oscillating as the cam revolves. When the cam itself oscillates, the *toe* and *wiper* are used, as at C. The toe, or follower, may also be made in the form of a swinging arm.

A *yoke* or *positive-motion cam* is shown at *D*, the enclosed follower making possible the application of force in either direction. The sum of the two distances from the center of the cam to the points of contact must always be equal to the distance between the follower surfaces. The cylindrical *groove cam* at *E* and the *end cam* at *F* both move the follower parallel to the cam

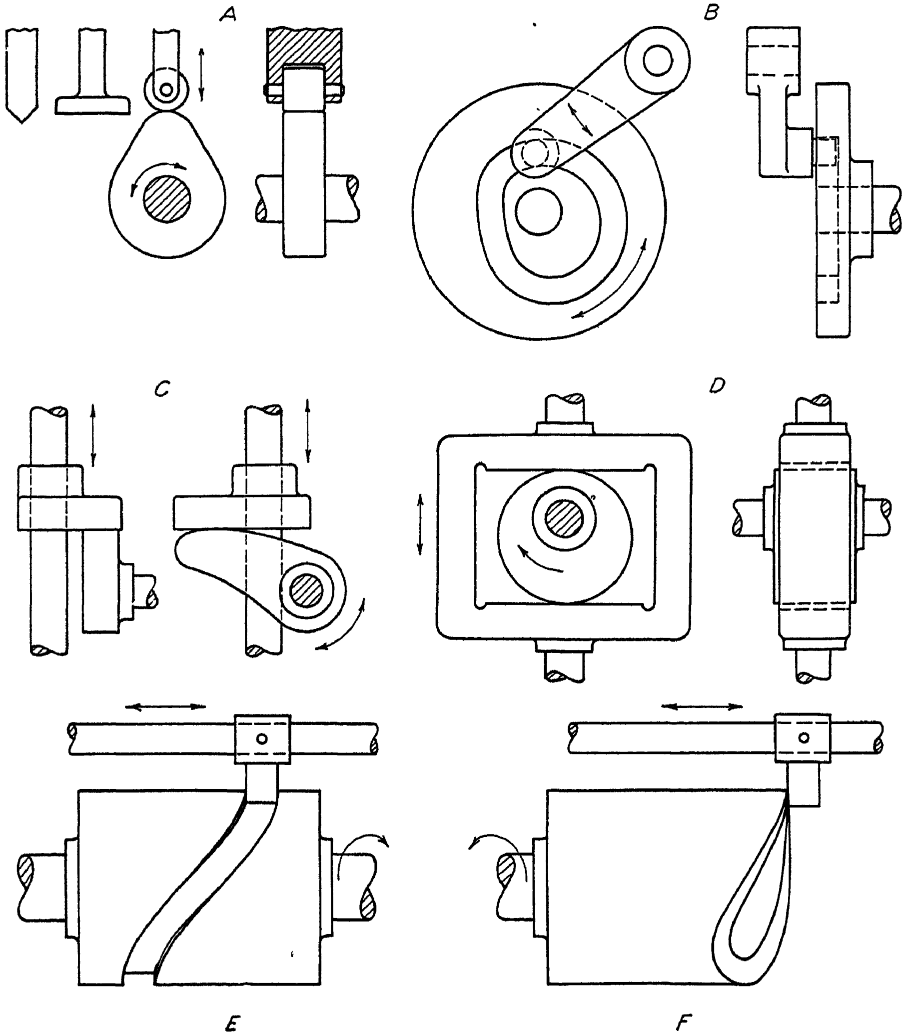


FIG. 714.—Types of cams.

axis, force being applied to the follower in both directions with the groove cam, and in only one direction with the end cam.

Kinds of Motion.—Cams may be designed to move the follower with constant velocity, acceleration or harmonic motion. In many cases, combinations of these motions, together with surfaces arranged for sudden rise

or fall, or to hold the follower stationary, go to make up the complete cam surface.

283. Cam Diagrams.—In studying the motion of the follower a diagram showing the height of the follower for successive cam positions is useful and is frequently employed. The cam position is shown on the abscissa, the full 360° rotation of the cam being divided, generally, every 30° (intermediate points may be used if necessary). The follower positions are shown on the ordinate, divided into the same number of parts as the abscissa. These diagrams are generally made to actual size.

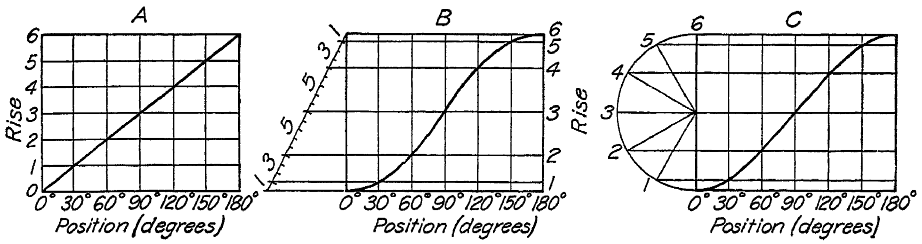


FIG. 715.—Methods of plotting cam diagrams; three kinds of motion.

Constant velocity gives a uniform rise and fall, and may be plotted as at *A*, Fig. 715, by laying off the cam positions on the abscissa, measuring the total follower movement on the ordinate and dividing it into the same number of parts as the abscissa. As the cam moves one unit of its rotation the follower likewise moves one unit, producing the straight line of motion shown.

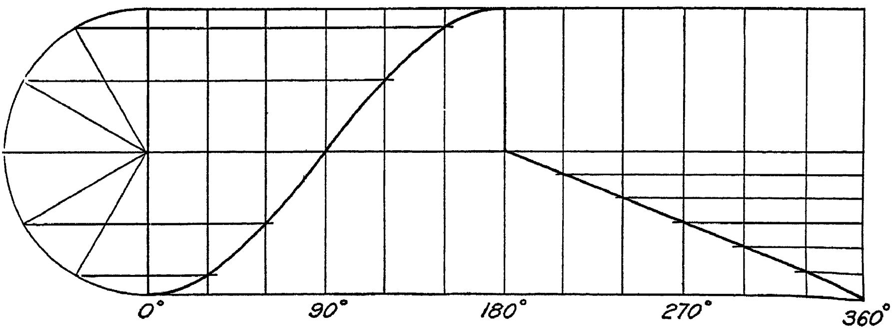


FIG. 716.—A cam diagram.

With constant acceleration, the distance traveled is proportional to the square of the time, or the total distance traveled is proportional to 1, 4, 9, 16, 25, etc., and if the increments of follower distance are made proportional to 1, 3, 5, 7, etc., the curve may be plotted as shown at *B*. Using a scale, divide the follower rise into the same number of parts as the abscissa, making the first part 1 unit, the second 3 units, and so on. Plot points at the intersection of the coordinate lines, as shown. The curve at *B* accelerates and then decelerates to slow up the follower at the top of its rise.

Harmonic motion (sine curve) may be plotted as at C by measuring the rise and drawing a semicircle, dividing it into the same number of parts as the abscissa and projecting the points on the semicircle as ordinate lines. Points are plotted at the intersection of the coordinate lines, as shown.

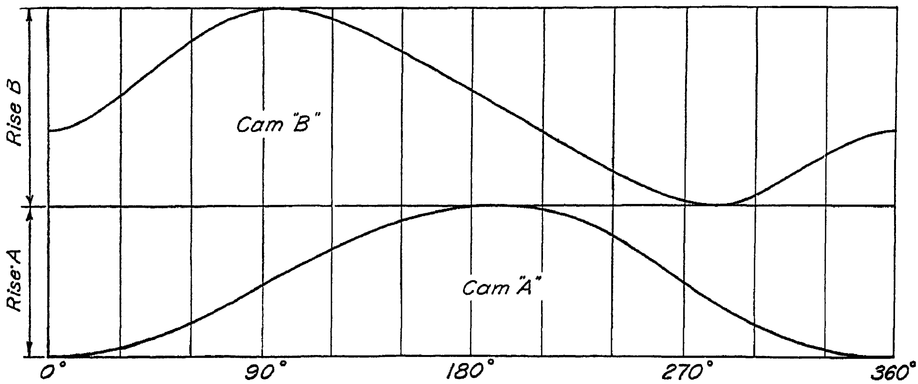


FIG. 717.—A timing diagram.

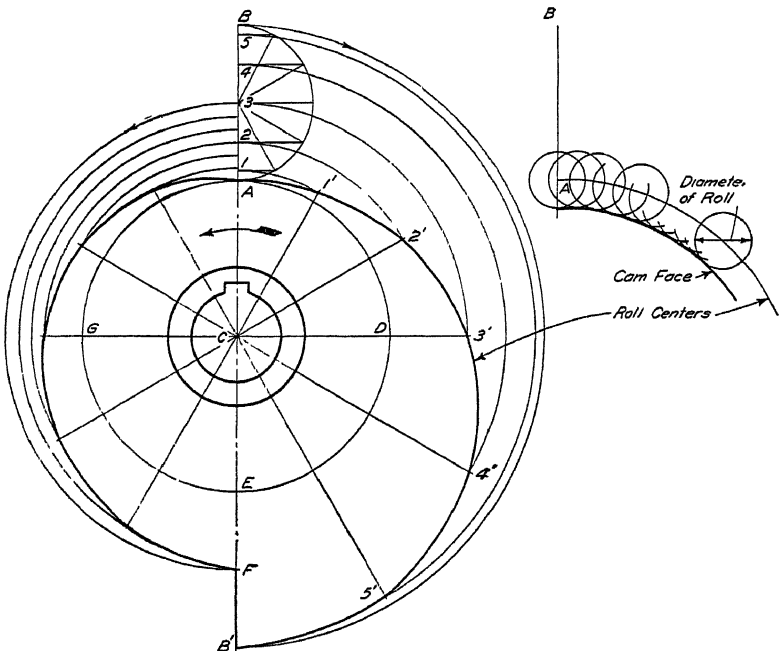


FIG. 718.—Layout of plate cam.

Figure 716 is the cam diagram for the cam of Fig. 718. The follower rises with harmonic motion in 180°, drops halfway down instantly and then returns with uniform motion to the point of beginning.

284. Timing Diagrams.—When two or more cams are used on the same machine and their functions are dependent on each other. the "timing" and

relative motions of each may be studied by means of a diagram showing each follower curve. The curves may be superimposed, but a better method is to place one above the other as in Fig. 717.

285. To Draw a Plate Cam.—The principle involved in drawing a cam is the same for all types. Illustrating with the cam of Fig. 718 for which the diagram of Fig. 716 was made, the point C is the center of the shaft, and A is the lowest and B the highest position of the center of the roller follower.

Divide the rise into six parts harmonically proportional. Divide the semicircle ADE into as many equal parts as there are spaces in the rise and draw radial lines. With C as center and radius $C1$, draw an arc intersecting the first radial line at $1'$. In the same way locate points $2'$, $3'$, etc., and draw

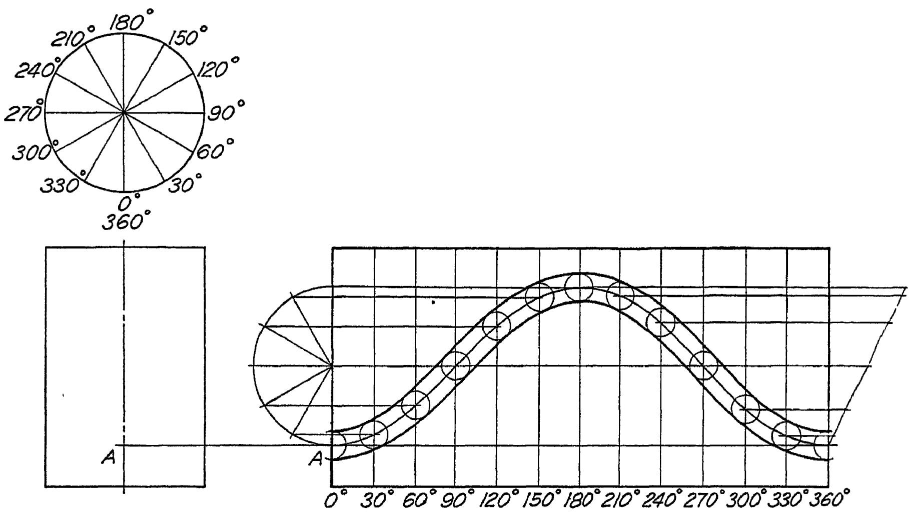


Fig. 719.—Layout of cylindrical cam.

a smooth curve through them. If the cam is revolved in the direction of the arrow, it will raise the follower with the desired harmonic motion.

Draw $B'F$ equal to one-half AB. Divide $A3$ into six equal parts and the arc EGA into six equal parts. Then for equal angles the follower must fall equal distances. Circle arcs drawn as indicated will locate the required points on the cam outline.

This outline is for the center of the roller; allowance for the roller size may be made by drawing the roller in its successive positions and then drawing a tangent curve as shown in the auxiliary figure.

286. To Draw a Cylindrical Cam.—The drawing of a cylindrical cam differs somewhat from that of a plate cam, as, in addition to the regular views, it generally includes a developed view, from which a template is made. Assume that the follower is to move upward $1\frac{1}{2}''$ with harmonic motion in 180°, and then return with uniform acceleration. Top and front views of the cylinder are drawn, Fig. 719, and the development of the surface laid out.

Divide the surface as shown, also the top view to show the positions of points plotted. Divide the rise for harmonic motion by drawing the semicircle and projecting the points. Refer to Fig. 715 *C*. Divide the return for acceleration as shown. Refer to Fig. 715 *B*. The curve thus obtained is for the center of the follower. Curves drawn tangent to circles representing positions of the follower will locate the working surfaces of the cam. The development made as described is the drawing used to make the cam.

PROBLEMS

Group I. Gears.

1. A broken spur gear has been measured and the following information obtained: number of teeth, 33; outside diameter, 4⅜″; width of face, 1″; diameter of shaft, ⅞″; length of hub, 1¼″. Make drawing of gear blank with all dimensions and information

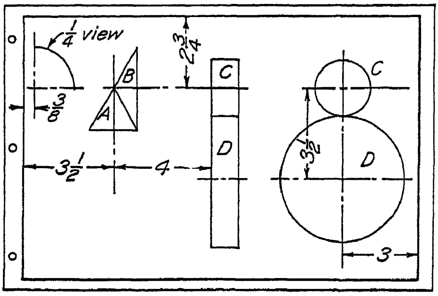


FIG. 720.

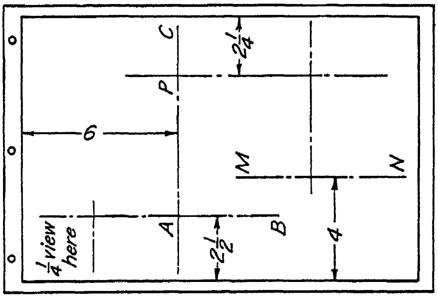


FIG. 721.

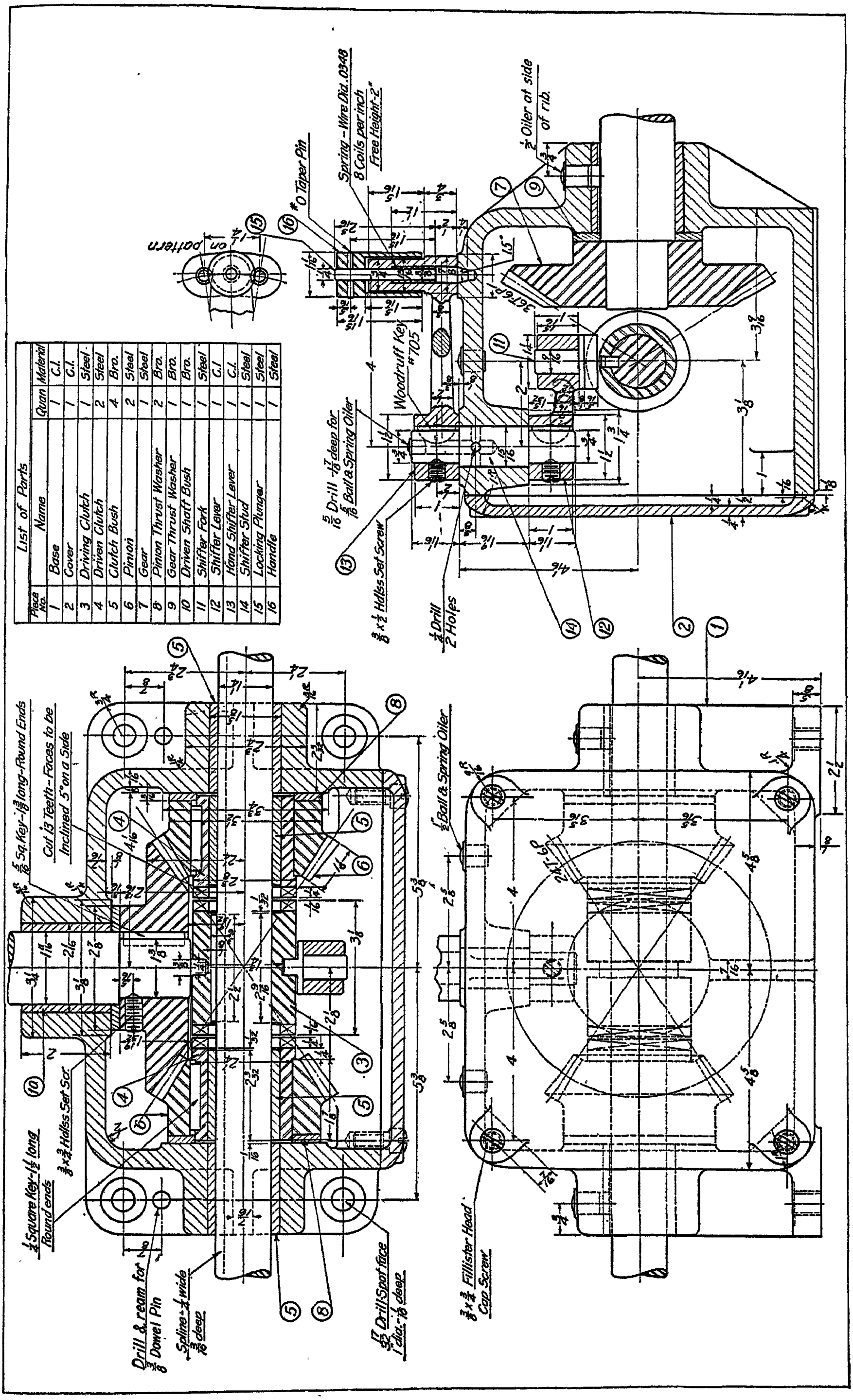
necessary for making a new gear. Dimensions not given above may be made to suit as the drawing is developed.

2. Make a drawing for a spur gear. The only information available is as follows: root diameter, 7.3372″; outside diameter, 8.200″; width of face, 1⅞″; diameter of shaft, 1⅜″; length of hub, 2″.

3. Make an assembly drawing of a pair of spur gears, from the following information: On an 11″ × 17″ sheet locate centers for front view of gear *B* 4½″ from right border and 3½″ from bottom border. Gear *A* is to the left of gear *B*. Center distance between gears is 5.250″. Gear *A* revolves 300 rpm and has four spokes, elliptical in cross section, 1″ major and ½″ minor axes; inside flange diameter 4⅜″; hub 2″ diameter, 1½″ long. Gear *B* revolves 400 rpm and is disk type with ½″ web; inside flange diameter 3¼″; hub 2″ diameter, 1½″ long. Material is cast steel; face width 1″; *DP* = 4; shaft diameters 1″, ¼″ Woodruff keys. Draw front view and sectional top view.

4. Fig. 720. Make an assembly drawing of gear train, as follows: *A* and *B* are bevel gears, ⅞″ face width, 6 *DP*. *A* has 3″ *PD*, revolves 150 rpm. *B* revolves 100 rpm. *C* and *D* are spur gears 8 *DP*, 1″ face width. *C* engages *D*, which revolves 40 rpm. All shafts 1″. Draw *A* in full section, *B* with lower half in section, *C* and *D* in full section, quarter end view of gear *B* in space indicated, and end views of *C* and *D*.

5. Fig. 721. A 3″-*PD* 3-*DP* bevel gear *R* on shaft *AB* running 1,120 rpm drives another bevel gear *S* on shaft *AC* at 840 rpm. On shaft *AC* centered at *P*, an 8″-*PD* 4-*DP* spur gear *T* drives a pinion *U* at 1,680 rpm. All shaft diameters 1″, face widths 1″. Hub diameters of *R* and *S*, 1¾″. Gear *C* has four spokes, elliptical, ⅝″ × 1″; hub 1⅞″ diameter; thickness of flange ½″. Draw gear *R* with upper half in section; *S*, *T* and *U* in full section. Put quarter end view of *R* in space indicated, and end views of *T* and *U* on center line *M-N*.



List of Parts

Piece No.	Name	Quan.	Material
1	Base	1	C.I.
2	Cover	1	C.I.
3	Driving Clutch	1	Steel
4	Driven Clutch	2	Steel
5	Clutch Bush	4	Bro.
6	Pinion	2	Steel
7	Gear	1	Steel
8	Pinion Thrust Washer	2	Bro.
9	Gear Thrust Washer	1	Bro.
10	Driven Shaft Bush	1	Bro.
11	Shifter Fork	1	Steel
12	Shifter Lever	1	C.I.
13	Hand Shifter Lever	1	Steel
14	Shifter Stud	1	Steel
15	Locking Plunger	1	Steel
16	Handle	1	Steel

FIG. 722.—Reversing mechanism.

6. Fig. 722. Make complete detail drawings of reversing mechanism, with bill of material and title. The purpose of this device is to drive a shaft in either direction from a shaft at right angles to it which always revolves in the same direction. In the design shown, either shaft may be driver, the gear ratios being 3 to 2.

The two bevel pinions, piece 6, are keyed to clutches, piece 4, which are bushed, piece 5, and run free on the splined shaft. These bevel pinions are always in mesh with the gear, piece 7, and, being on opposite sides of it, revolve on the splined shaft in opposite directions. The clutch, piece 3, is splined to its shaft and is free to shift axially into mesh with either of the two clutches, piece 4. This movement is controlled by the shifter arrangement, pieces 11, 12, 13, 14, 15 and 16. Three reamed tapered holes are provided in the pad on the top of the housing for the locking plunger, piece 15. This ensures positive retention of the clutch in either neutral or driving positions.

7. Fig. 722. Make assembly drawing of reversing mechanism, with title and piece numbers.

8. Fig. 722. Redesign reversing mechanism for complete ball-bearing installation.

9. Fig. 722. Redesign reversing mechanism with gear ratio 7 to 4 instead of 3 to 2.

10. Fig. 722. Redesign reversing mechanism as follows: Gear ratios 7 to 5 instead of 3 to 2; all thrust requirements to be met by ball-bearing installation. Spline shaft diameters to be 1″ instead of 1¼″. Keyed shaft to be 1⅛″ instead of 1⅜″. Use one centralized oiling system for the whole mechanism.

11. Fig. 722. Redesign reversing mechanism for splash lubrication. Provision must be made for retaining the oil at cover joint and where shafts enter the box. Do not neglect to provide filling and draining plugs and an oil-level gage.

12. Fig. 722. Redesign reversing mechanism as follows: make pieces 3, 4 and 6 in one piece, and spline to shaft as in present design. This will dispense with the two bushings, piece 5, and also the clutch teeth. This new piece is called a "double bevel gear" and should be made long enough to be shifted axially in and out of mesh with gear, piece 7. Be sure to provide a neutral position. This design requires the thrust of the bevel gears to be taken by the shifter fork, which should be redesigned to take this load. It is suggested that a double fork of bronze be used with a strengthened locking plunger.

13. Fig. 723. Four-speed machine-tool transmission box. The power comes in on shaft A at a constant rate and leaves on shaft B at a rate depending on the positions of the sliding gears. Only the top view and end in section are given. The detail drawing of the gear-shifter bracket is shown in Fig. 607. Make a complete assembly drawing showing the front, top and end views.

14. Fig. 723. Make complete working details with bill of material from the design of Prob. 13.

15. Fig. 723. Redesign Prob. 13 for ball-bearing installation.

16. Fig. 723. Redesign Prob. 13 for speed ratios 1 to 1, 1 to 1.228, 1 to 1.437 and 1 to 1.776, making pieces 1 and 6 duplicates. Shaft centers are to remain as in Prob. 13. Note that in the required set of speeds the ratio between each successive speed is approximately a constant (1.2).

17. Fig. 723. Redesign Prob. 13, using gears ¾″ wide, shafts A and B to be 1⅜″ in diameter. Omit center bearing for jack shaft but leave the shaft diameter unchanged.

Group II. Cams.

18. Make a drawing for a plate cam to satisfy the following conditions: On a vertical center line a point A is ⅞″ above a point O, and a point B is 1¾″ above A. With center at O, revolution clockwise, the follower starts at A and rises to B with uniform motion during one-third revolution, remains at rest one-third revolution, and drops with uniform motion the last one-third revolution to the starting point. Diameter of shaft ¾″; diameter of hub 1¼″; thickness of plate ½″; length of hub 1¼″; diameter of roller ½″.

19. Make a drawing for a face cam, using the data of Prob. 18.

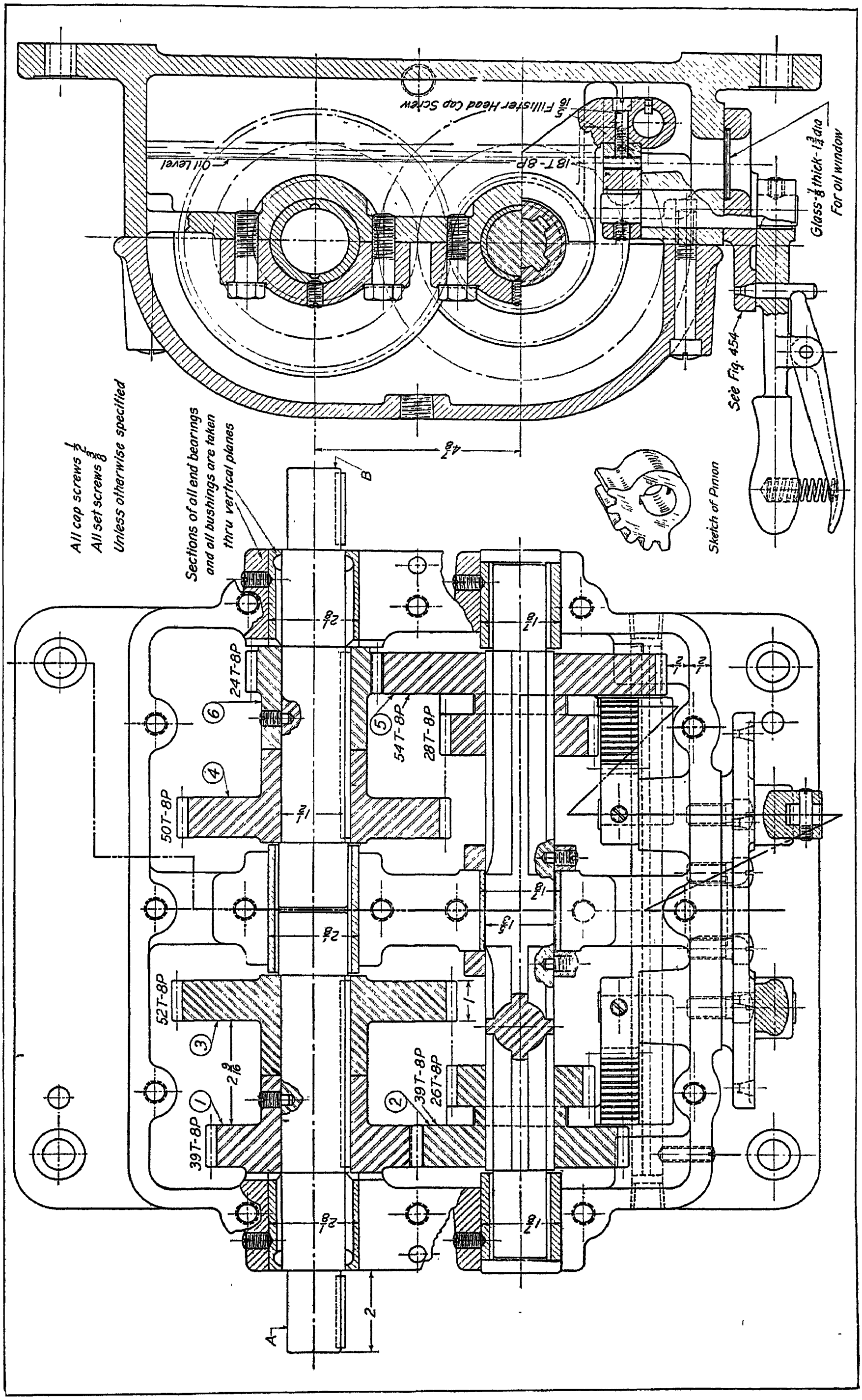


FIG. 723.—Transmission box.

20. Make a drawing for a toe-and-wiper cam. The toe shaft is vertical, $\frac{3}{4}''$ in diameter. Starting at a point $1''$ directly above center of wiper shaft, the toe is to move upward $2''$ with simple harmonic motion, with $45°$ turn of the shaft. Wiper has $1\frac{1}{4}D$ hub, $1\frac{1}{4}''$ long; $\frac{3}{4}''$ diameter shaft. Design toe to suit.

21. Make a drawing for a positive-motion cam. Starting at a point $1''$ above center of cam shaft, upper follower surface is to move upward $1''$ with simple harmonic motion in $180°$ turn of cam. Return is governed by necessary shape of cam. Follower $\frac{1}{2}''$ thick on $\frac{1}{2}''$ vertical shaft. Cam $\frac{1}{2}''$ thick, on $\frac{3}{4}''$ diameter shaft; hub $1\frac{1}{4}''$ *D*, $1\frac{1}{4}''$ long.

22. Make a drawing, with development, for a cylindrical cam. The $\frac{1}{2}''$ *D* roller follower is to move $2''$ leftward with constant velocity in $180°$ turn of cylinder and return with simple harmonic motion. Cam axis horizontal, cylinder $4''$ *D*, $4''$ long on $1''$ shaft. Follower pinned to $\frac{5}{8}''$ shaft $3''$ *c* to *c* from cylinder.

CHAPTER XVII

JIGS AND FIXTURES

287. Jigs and fixtures are devices for holding the work and guiding the tools for machining operations on pieces made in interchangeable quantity

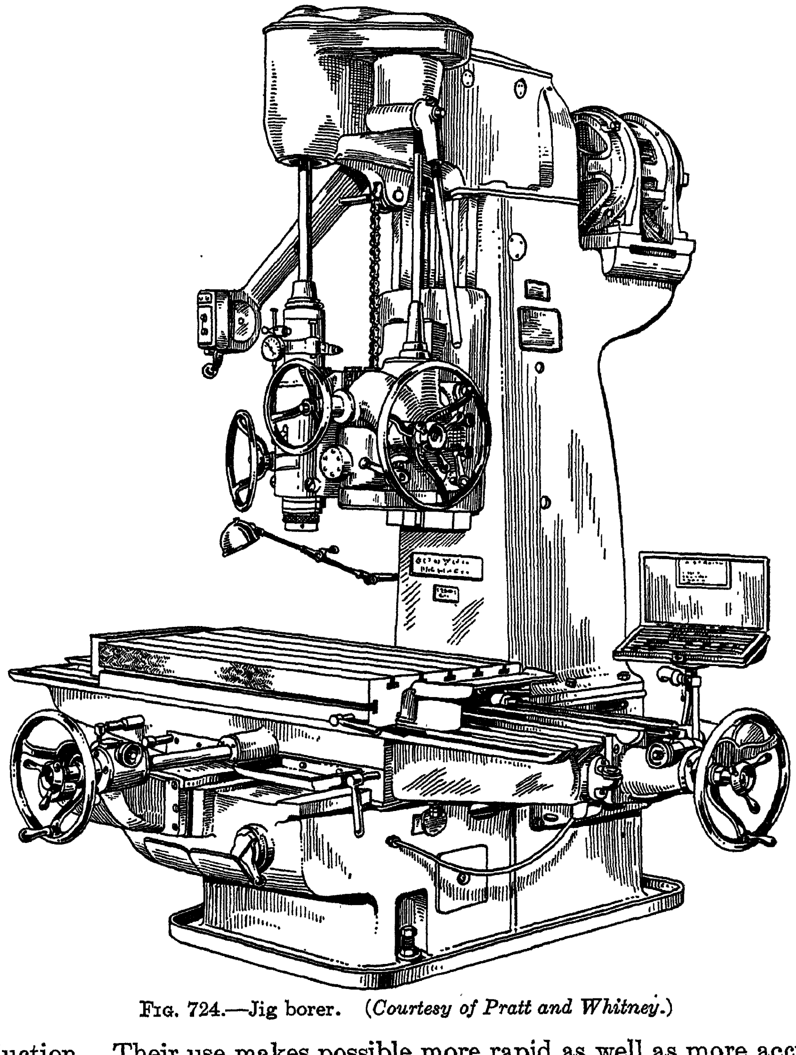


FIG. 724.—Jig borer. (*Courtesy of Pratt and Whitney.*)

production. Their use makes possible more rapid as well as more accurate manufacturing at a reduction of cost. In general the distinction between a

jig and a fixture is that a jig clamps or is clamped to the work and guides the various tools into position, while a fixture is fastened to the machine and holds the piece in a definite position but does not guide the cutting tool. The object to be machined, usually termed "the production," or "the subject," may, for example, require the drilling of several holes or their drilling and tapping, drilling and counterboring, or drilling and reaming. The particular jig designed to aid in these operations would be called a "drill jig," "drill-and-tap jig," "drill-and-counterbore jig" or "drill-and-ream jig." If the operation to be performed is to face the end of a cylinder, the device for holding the production would be called a "facing fixture." If the production is to be held while a hole is bored in it on a lathe, the holding device would be a "boring fixture."

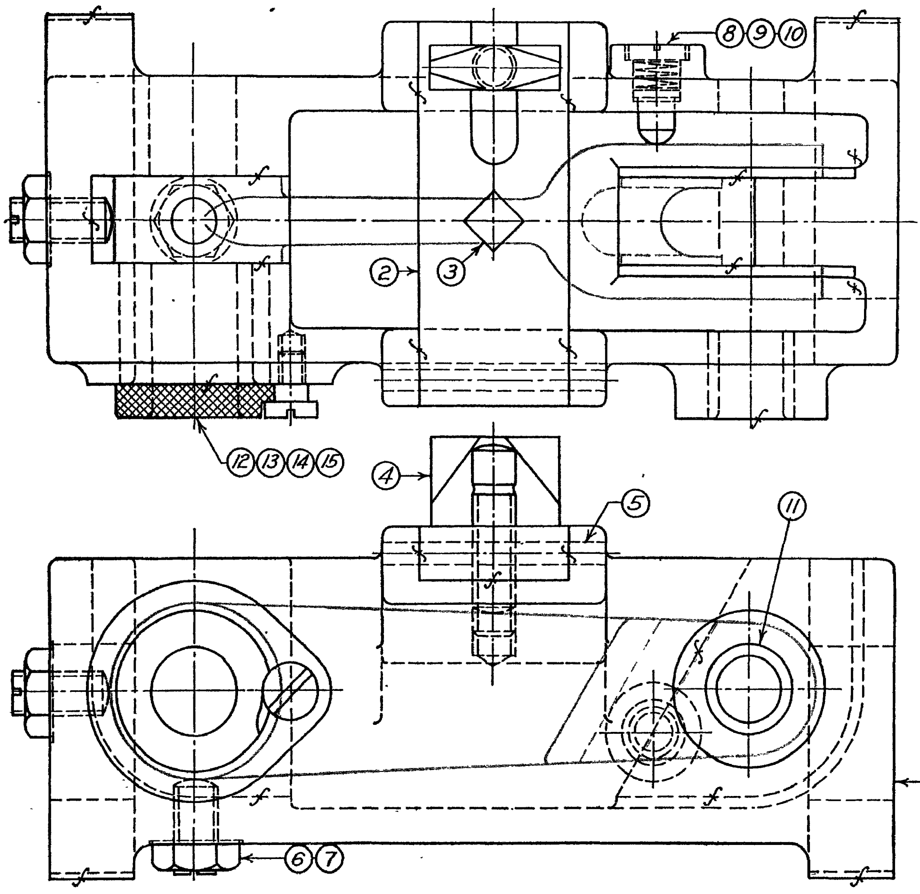
288. Production Cost.—Whether or not to use a jig depends on two items: first, the number of pieces to be machined and, second, the accuracy demanded. The cost of producing the part individually should be figured carefully and compared to the cost of producing with a jig, in each case measuring time from the starting of one piece to the starting of the next piece, and using the current wage scale of the kind of operators required. The estimated cost of making the jig will then answer the question. In the same way the saving in time by the use of a more expensive jig over a cheaper one should be studied.

289. Jig Borers.—When relatively few pieces are to be drilled it may be cheaper to machine them individually, either on a drill press or, very much more accurately, on a jig borer, Fig. 724. If many are required, such as parts for automobiles and similar large-quantity work, a jig is indispensable for accuracy, speed, interchangeability and reduction of cost. The correct procedure therefore is to use the jig borer to construct a jig (the purpose for which the jig borer was designed), and use the jig for accurate, interchangeable products done on machines cheaper and speedier than the jig borer and operated by almost unskilled labor.

In a job shop making parts to be cast and finished but assembled at another place, orders might call for from ten to a hundred or a thousand machines, with repeat orders later, and the jigs would assure the same degree of accuracy in all the production pieces.

290. Principles of Design.—To illustrate some of the principles of jig design, a simple jig for drilling two $\frac{3}{4}''$ holes and reaming one $1''$ hole in the pawl carrier of Fig. 617 is shown in Fig. 725. These principles, which should be followed as far as possible, are

1. The production must go into the jig easily and quickly.
2. The production must be located accurately.
3. The bushings must be accessible to the operator.
4. The production must be securely clamped in the jig.
5. The production must be removable easily and quickly.



ITEM	NAME	MAT'L	DESCRIPTION
1	Body	C.I	
2	Clamp	C.R.S	
3	Set Screw	Std	$\frac{1}{2} \times 1\frac{3}{8}$ Sq.Hd Rd Pt.
4	Quarter Turn Scr.	C.R.S.	$\frac{1}{2}$-13NC-2 Thd.
5	Hinge Pin	D.Rd	$\frac{1}{4} \times 2\frac{5}{8}$ Lg.
6	Set Screw	Std.	$\frac{1}{2} \times 1\frac{1}{8}$ Slot Hd.'less Rd. Pt.
7	Hex. Nut	Std.	$\frac{1}{2}$-13NC-2
8	Pop Pin	T.S.	
9	Spring	Stl.	To Suit
10	Screw Plug	"	$\frac{3}{4}$-10NC-2 × $\frac{3}{16}$ Lg.
11	Drill Bushing	"	For $\frac{3}{4}$ Drill 1" D. × 1" Lg.
12	Liner "	"	$1\frac{3}{4}$ D. × $1\frac{3}{8}$ Lg.
13	Slip "	"	For $\frac{63}{64}$ Drill
14	" "	"	For 1.000 Ream
15	Lockscrew	Std.	$\frac{5}{16}$-18NC-2

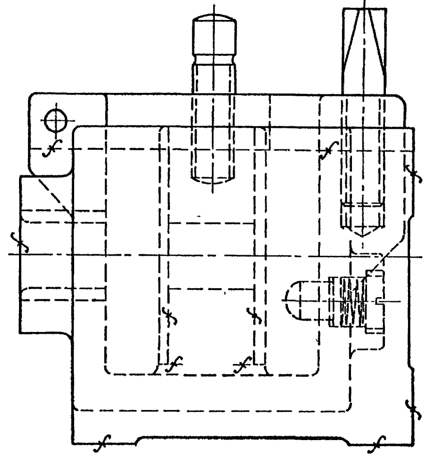


FIG. 725.—Jig for pawl carrier.

Note incidentally that it is universal practice in jig drawing to show the production in *red*, while the jig itself, in black, is drawn, as to visibility, as if the production was not in place.

In this example, and in all other designs, four main points of design involved in the above principles must be observed. Briefly these are

1. Locating the production.
2. Clamping the production.
3. Selecting bushings of correct style and size.
4. Designing the jig body to accommodate the production and satisfy the principles.

By following these four cardinal points a drill jig can be designed that will satisfy the requirements of commercial production. Each point involves careful study to decide upon the most suitable of many methods to use in combination with the others. Several types in each division will

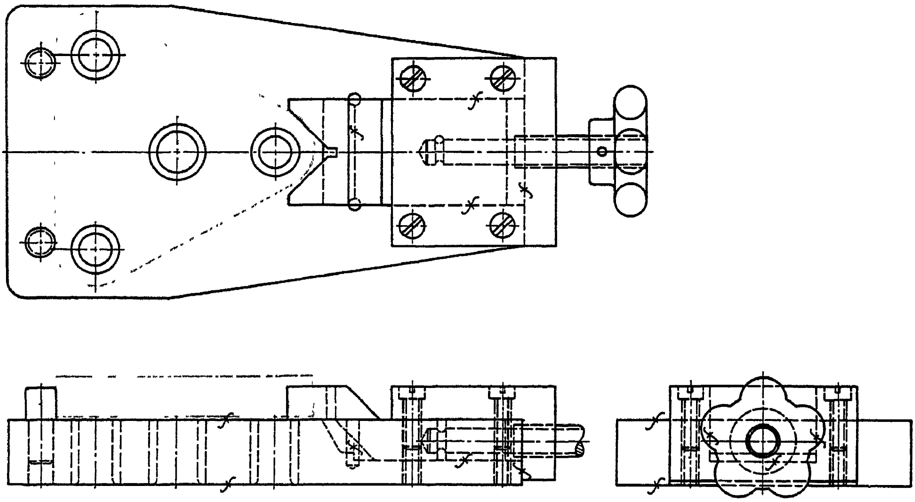


FIG. 726.—Jig for cover plate.

be discussed, but the reader will understand that he is not confined to these only, in designing some particular piece of work.

291. Locating the Production.—The shape of the production, previous milling and finishing before drilling, and other points of design will influence the type of locator best suited for the production. Location must be thoroughly considered, as it is perhaps the most important of the four points, from the standpoint of accuracy in the jig.

Finished surfaces are often used to locate. A finished surface of the production is placed against a finished surface of the jig; or when necessary, even an unfinished surface of the production is placed against a finished surface of the jig. Location surfaces may take the form of pads, counterbores or two finished surfaces at right angles to each other.

Pins give an easy and relatively inexpensive method of location and at the same time a very accurate one. A finished or an unfinished surface of

the production is held against a pin and a finished surface, or against either two, or three pins, by a clamp or screws, Fig. 726.

In the fixture of Fig. 729, two pins, one circular and the other flattened, are used to locate. Both pins are accurate to the size necessary to fit into two previously drilled or reamed holes in the production. (One pin must be flattened because the center-to-center distances of the holes may vary enough to make a fit impossible with two round pins.) The round pin locates along the line of centers, and both pins locate at right angles to the line of centers, since the flats of the flattened pin are always placed per-

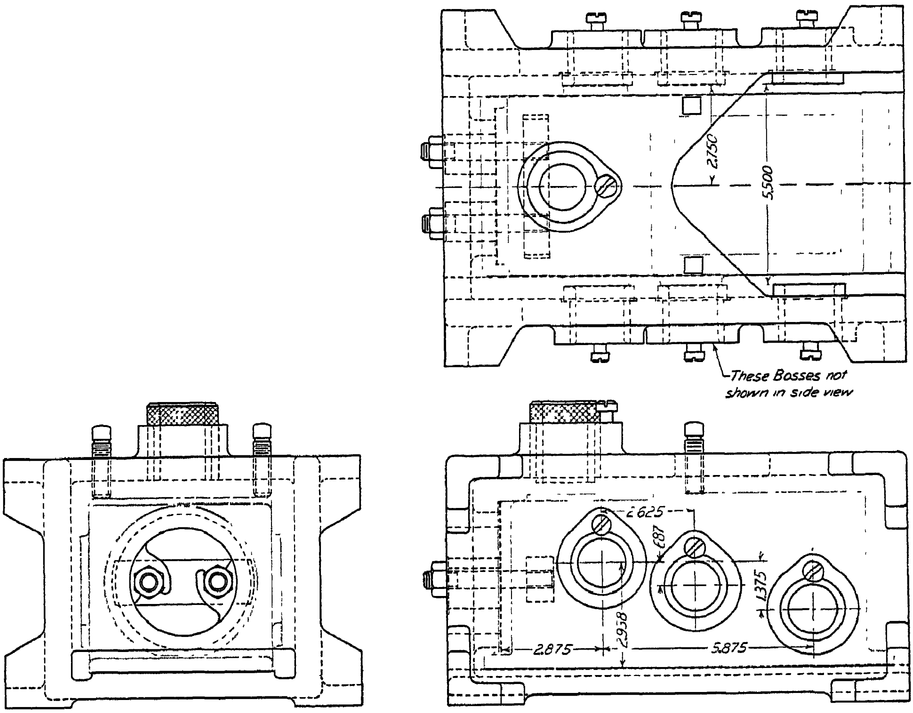
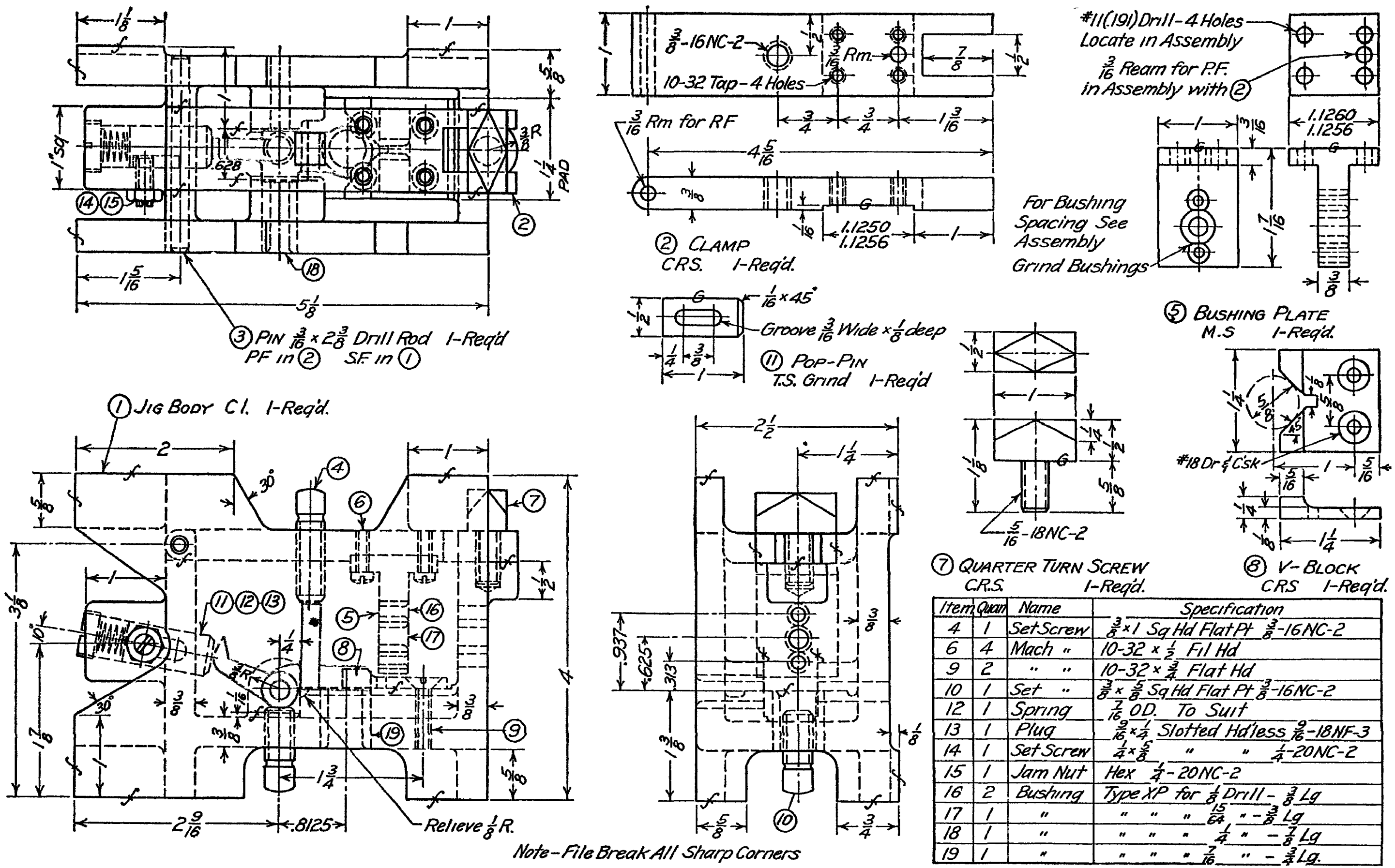


FIG. 727.—Drill and ream jig for gear case.

pendicular to the line of centers. Note that the pins are made so that they can be pressed into the fixture only up to the shoulder. The ends are chamfered, preferably at 30 degrees, to allow easy entry into the production.

Small pins are usually made of tool steel, hardened and ground. Large pins may be made of cold-rolled steel, pack-hardened and ground. They should not be cyanided, as this does not give sufficient depth of hardening, and the grinding of a cyanided piece is not successful. The shoulder of the pin is pressed against a finished surface or into a light spot face or counterbore to a suitable depth.

Bushings serve as locators in certain designs, as illustrated in Fig. 727. This jig is to serve in drilling and reaming holes in a gear case, on which the



Item	Quan	Name	Specification
4	1	Set Screw	$\frac{3}{8}$ × 1 Sq Hd Flat Pt $\frac{3}{8}$-16NC-2
6	4	Mach "	10-32 × $\frac{1}{2}$ Fil Hd
9	2	" "	10-32 × $\frac{3}{4}$ Flat Hd
10	1	Set "	$\frac{3}{8}$ × $\frac{5}{8}$ Sq Hd Flat Pt $\frac{3}{8}$-16NC-2
12	1	Spring	$\frac{7}{16}$ OD. To Suit
13	1	Plug	$\frac{9}{16}$ × $\frac{1}{4}$ Slotted Hdless $\frac{9}{16}$-18NF-3
14	1	Set Screw	$\frac{1}{4}$ × $\frac{5}{8}$ " " $\frac{1}{4}$-20NC-2
15	1	Jam Nut	Hex $\frac{1}{4}$-20NC-2
16	2	Bushing	Type XP for $\frac{1}{8}$ Drill - $\frac{3}{8}$ Lg
17	1	"	" " " $\frac{15}{64}$ " - $\frac{3}{8}$ Lg
18	1	"	" " " $\frac{1}{4}$ " - $\frac{7}{8}$ Lg
19	1	"	" " " $\frac{7}{16}$ " - $\frac{3}{4}$ Lg.

FIG. 728.—Jig for trip arm.

out-to-out distance between bosses is an accurate dimension with limits; hence the surfaces of these bosses provide good points for location, and the accurately located shoulder bushings are designed to come to contact with them. Location of the subject in the other directions is by using finished surfaces, against which it is clamped by screws and a bar clamp.

V-blocks are often used in jig design, both as locators and as clamps. An example was seen in Fig. 726. The jig of Fig. 728 employs a V whose purpose is mainly for location, though it also serves as a "backstop" in clamping, while the setscrews are the clamps proper. A V-block is more easily made as a separate piece, secured to the body of the jig by screws and dowel pins. Fastening the V-block without dowel pins, by using slotted holes for the cap screws, might be necessary in case the circular boss on the production varied considerably in diameter with different castings.

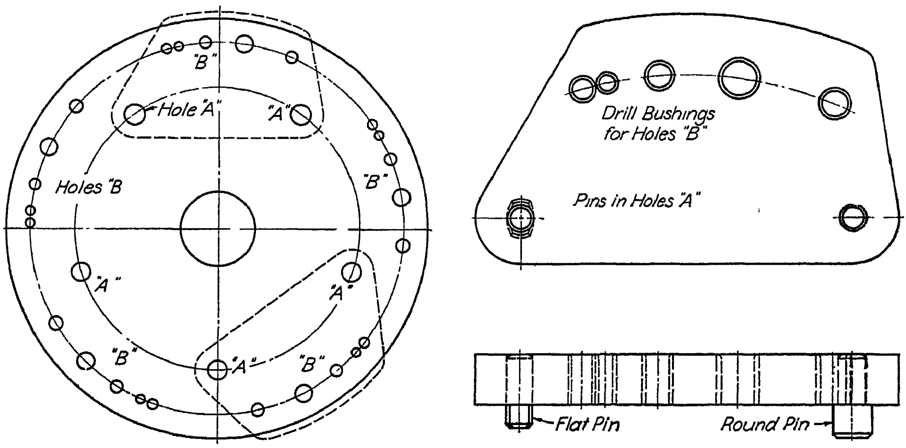
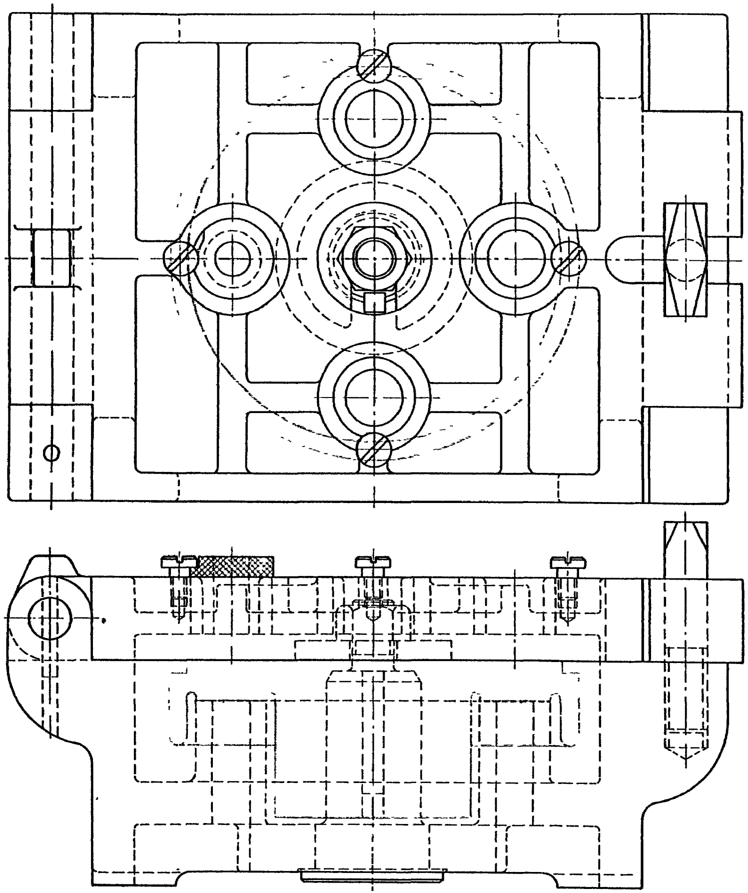


FIG. 729.—Jig for making a jig.

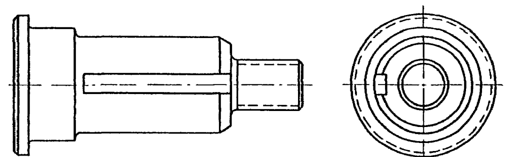
Accurate Holes for Pins.—A small plate jig is often used to drill a recurring series of holes in making a large jig, Fig. 729, or in a production itself. The small jig carries two locating pins, one round and the other flattened for reasons already mentioned. On the large jig the holes marked *A* have been previously drilled and reamed, either with the jig borer or on a radial boring machine, to match the pins of the small jig, through whose use the series of holes may then be drilled with far more accuracy and speed than if each hole had to be located individually.

Center Locators.—The jig of Fig. 730 uses a center locator. If the hole in the production is of such size that it has been bored on a lathe and the piece faced at the same time, this method of locating is indicated. The shank for locating is of such diameter that the hole is a slip fit over it. Either a class 2 or 3 ASA fit could be used, depending upon the accuracy of drilling required.

Keyways serve as locators in cases where it is necessary to drill holes that must be in a particular position. In a jig designed for the coupling of



BILL OF MATERIAL				
Item	Name	Quan	Matl.	Description
1	Jig Body	1	CI	
2	Bushing Plate	1	CI	
3	Quarter Turn Screw	1	MS	
4	Pin	1	CRS	$\frac{3}{4}$D × 8$\frac{5}{8}$ SF in ① RF in ②
5	Pin	1	CRS	$\frac{1}{4}$D × 1$\frac{1}{2}$ Drive Fit in ① and ④
6	Hex Nut	1	Stl	$\frac{7}{8}$-9NC-2 Std
7	Locator	1	"	See Detail
8	Liner	4	"	Type XL-64 ASA Std
9	Bushing	1	"	" R-64 " " $\frac{5}{8}$ Drill
10	"	1	"	" " " " " $\frac{41}{64}$ Ream
11	Lockscrew	4	"	No 2A ASA Std
12	C-Washer	1	CRS	



DETAIL OF LOCATOR

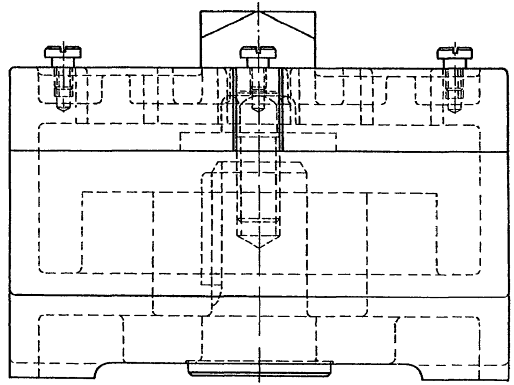


FIG. 730.—Drill and ream jig, using center locator.

Fig. 612, where the holes must be in the center of the bosses and at the same time be located with respect to the keyway, the center locator would include a key to slip into the keyway of the subject.

292. Clamps and Clamping.—Some of the more commonly used clamps for fastening the subject securely in the jig are the following:

1. Bar clamp.
2. Slotted clamp.
3. Setscrews and studs.
4. C-washer.
5. V-slide.
6. Spiral-rise cam.
7. Star knob and stud.
8. Adjustable pins.
9. Hydraulic piston.

The jigs illustrated in this chapter show several of these methods of clamping. The important point to observe is that *the clamp must not distort the production, as such distortion introduces inaccuracy in the drilled holes upon release of the clamping pressure. Clamping must be applied at a point on the production that will withstand the strain introduced,* and as close as possible to the point drilled. This last cannot always be made to apply, but it should be considered carefully.

Clamps suffer the most wear of any part of a jig, and cyanide hardening is advisable. Where there is a possibility of marring a finished surface a soft-nosed clamp should be employed.

Slotted clamps are widely used. To get proper action they should have the stud at the center or closer to the production than to the tail of the clamp. Studs and nuts are preferred over cap screws, as they do not wear out the body of the jig, and may be replaced cheaply.

Setscrews are cheap and highly efficient as a means of holding the production securely, Fig. 728. In clamping four sides of an object, the setscrews on two sides will have lock nuts, and those on the other two sides will be used for locking and unlocking the piece.

Use may be made of a stud and nut in combination with a C-washer in cases where the production slips over the stud or a locating pin, Fig. 730.

V-Slide.—The principal precaution in the use of the V-slide in clamping is to see that its length is at least equal to its width, to avoid having an unstable action. Its thickness depends upon the production and whether the slide is fixed or movable. In the latter case the size of the control screw will have a bearing on the thickness.

Spiral-rise cam clamps are useful in quantity production where quick clamping and unclamping with little thought required from the operator are the prime requisites. The maximum variation in the production pieces at the point of clamping must be known, from which the rise of the cam is computed, in order that the cam face will clamp the production with a 90°

turn of the handle. Figure 731 shows two types of locking cams which give locking action in either of two directions from the axis.

Star knobs and studs are an adaptation of the setscrew principle for hand operation.

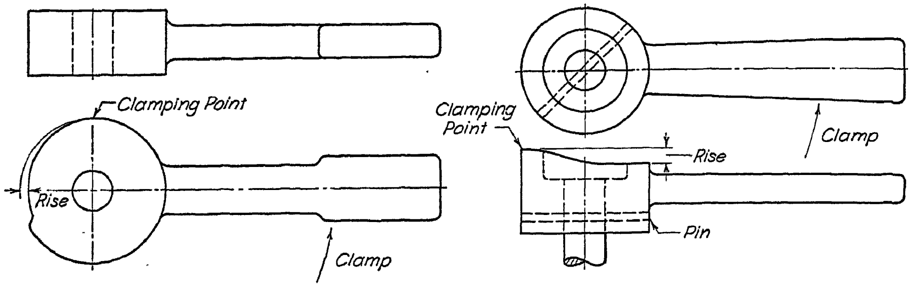


FIG. 731.—Spiral rise cam clamps.

Adjustable pins are used to support fragile sections of the production. Correct designs are shown in Fig. 732. They should be locked into position by a setscrew.

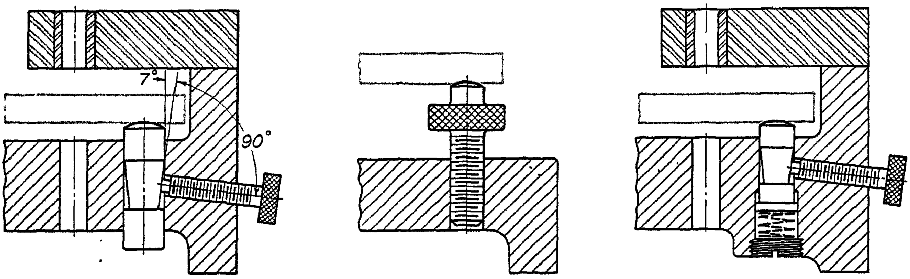


FIG. 732.—Three methods of supporting fragile sections.

Hydraulic pistons are for heavy work and work requiring special clamping. Their design is of too specialized a nature to be included here.

293. ASA Bushings.—Drill bushings are standardized items, made in all the number, letter, and fractional drill sizes up to 2 inches, in five different styles and six to eight lengths in each style, Fig. 733. See page 600 for types.

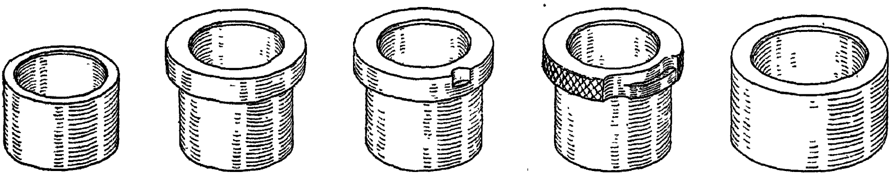


FIG. 733.—ASA standard jig bushings.

The plain stationary press-fit bushing, type *P*, is pressed into a bored or reamed hole, as is also the shoulder bushing, type *S*.

The type *RS* bushing, with liner and lock screw, is used where quantity production makes it necessary to replace worn-out bushings frequently.

Removable slip bushings, type R, are used where drilling is followed by reaming, tapping, counterboring, spot-facing, etc., without removing the production from the jig. They should be used in combination with a liner and lock screw unless the design cannot possibly allow the additional space required by the liner.

For correct installation, design drawings should show clearly the bell-mouthed end of the bushing as the entry end for the drill. For accurate drilling the other end should be not more than one drill diameter from the production. The thickness of the production, type of material being drilled and the design of the jig will all influence the minimum distance between the end of the bushing and the production. Chip clearance must be considered to avoid drill binding and the creation of unusual pressures. Sometimes the bushing is designed to touch the production, and the chips are carried up and out at the top.

Most job shops prefer to use the type of bushings that have $\frac{1}{64}''$ grinding stock on the outside diameter, for fitting the bushing to the hole. These are denoted by the prefix X, as XP, XS, etc.

Bushings for special work should be described by following the tables of standard wall thicknesses, size of head, etc., and specifying the proper finish and heat-treatment.

294. The Jig Body.—Jig bodies are of two general classes: the open body and the closed or box type. In general, open jigs have drill bushings in the same plane, parallel to one another. The second, box-shaped, type is for drilling holes from various planes and directions. Occasionally there may be an overlap in the nomenclature of the two general types.

On account of the required rigidity, cast iron has been the usual material for jig bodies, but welded steel is now being used successfully.

Judgment should be given to the weight of the body. For ease of handling it should have no excess weight but must not be lightened at any expense of the stiffness and rigidity necessary for accuracy. It is often possible, however, to core out metal in various places without decreasing strength. For the comfort and safety of the operator, corners should be rounded and all burrs and sharp edges removed by filing. For convenience in moving, small jigs may be equipped with handles, and large ones with hooks for handling with a crane.

Finished feet should be provided on the sides opposite the drill bushings. For proper machining, small lugs are often placed on other sides to act as stops. The jig feet are generally part of the casting but in some cases are inserts. Four should always be used in preference to three, because with four feet any unevenness in setting, such as a chip under one foot, will at once draw the attention of the operator, by rocking.

On the inside of the jig and at other places where machining is to be done, particular care should be taken to allow proper clearance for the machining tools. Points of location should, if possible, be visible to the operator.

Small jigs do not need to be clamped to the table, but large jigs and all fixtures should be provided with means of clamping securely to the machine on which they are used.

295. Summary. Fourteen Points in Jig Design.

1. Provide best method of locating.
2. Provide best method of clamping.
3. Select correct types of bushings.
4. Have bushings accessible to operator.
5. Design for quick loading and unloading.
6. Design for ability to withstand abuse without affecting accuracy.
7. Keep in mind the safety of the operator.
8. Provide clearance for drills after passing through the work.
9. Provide for chip clearance and easy removal of chips.
10. Design so that cheaper parts wear out first.
11. See that finished surfaces will not be marred by clamping devices.
12. Provide means for lifting heavy jigs.
13. If loose parts are unavoidable, chain them to the body of the jig.
14. Consider the cost of materials and labor, but do not attempt to cut the cost of the jig at the expense of efficiency of the design.

296. Making a Jig Drawing.—The drafting-room procedure in designing a jig or fixture should follow approximately this order:

1. Sketch the design freehand, to get the proper choice of views and an idea of space requirements. This original sketch will take into account previously finished surfaces of the production.
2. Allowing ample space between views, carefully draw the production in red in its several views.
3. Build the jig around the production, following the correct principles of location, clamping, bushings and body design.
4. Dimension the drawing of the jig, using decimal dimensions for all locators and bushings, following the system of base-line dimensioning, from zero coordinate axes. See Fig. 467.
5. Give each part an item number.
6. Prepare a bill of material of all items in sequence.
7. Check the drawing.

297. Fixtures.—Two examples are given here to illustrate the many uses of fixtures in quantity production. Figure 734 is a fixture to aid in boring the hole and facing the projection and bottom of the flange of Fig. 401. The flange locates over the pins. The center clamp is removed, and slotted clamps are used while the hole and projection are being machined. To complete the finishing of the bottom the clamps are slid back, and the center clamp is put in place.

Figure 735 is a fixture for holding the offset bracket of Fig. 308 in boring the hole and facing the end. The bracket locates over two pins and is held in place by the clamp.

Both these fixtures clamp to the faceplate of the lathe, the entire fixture and production rotating. Being unbalanced, the offset bracket fixture requires a counterbalance to reduce vibration and aid in accuracy of work.

PC.NO.	NAME	MAT'L
1	Face Plate	C.I.
2	Locating Pin	T.S.
3	" "	"
4	Clamp	C.R.S.
5	Stud	"
6	Hex. Nut	St'd.
7	Clamp Seat	M.S.
8	Fil. Hd Cap Scr.	St'd.
9	Centering Stud	C.R.S
10	Hex. Nut	St'd.
11	C-Washer	C.R.S
12	Spring	St'l.

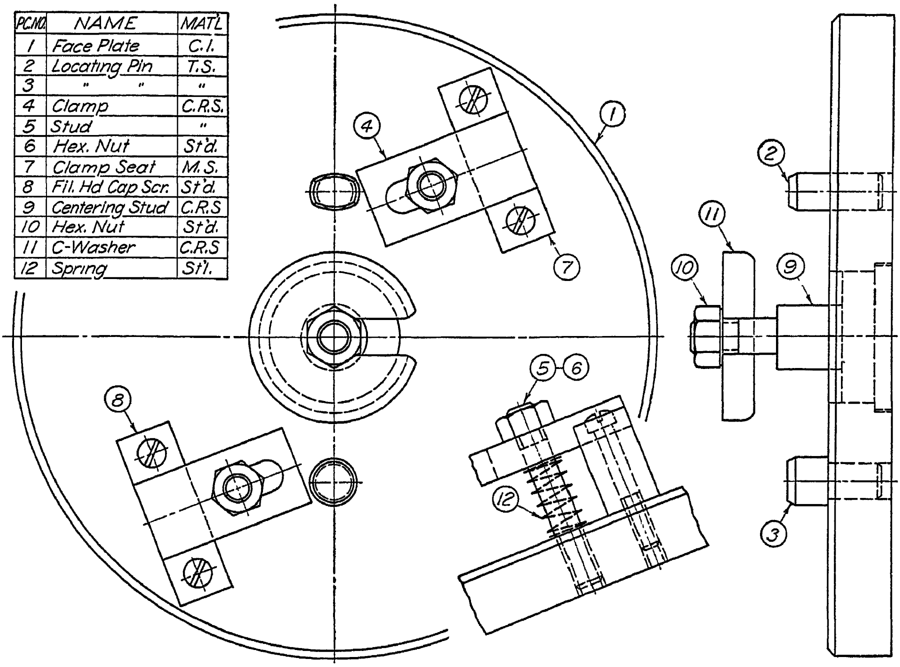


FIG. 734.—Lathe fixture for boring and facing.

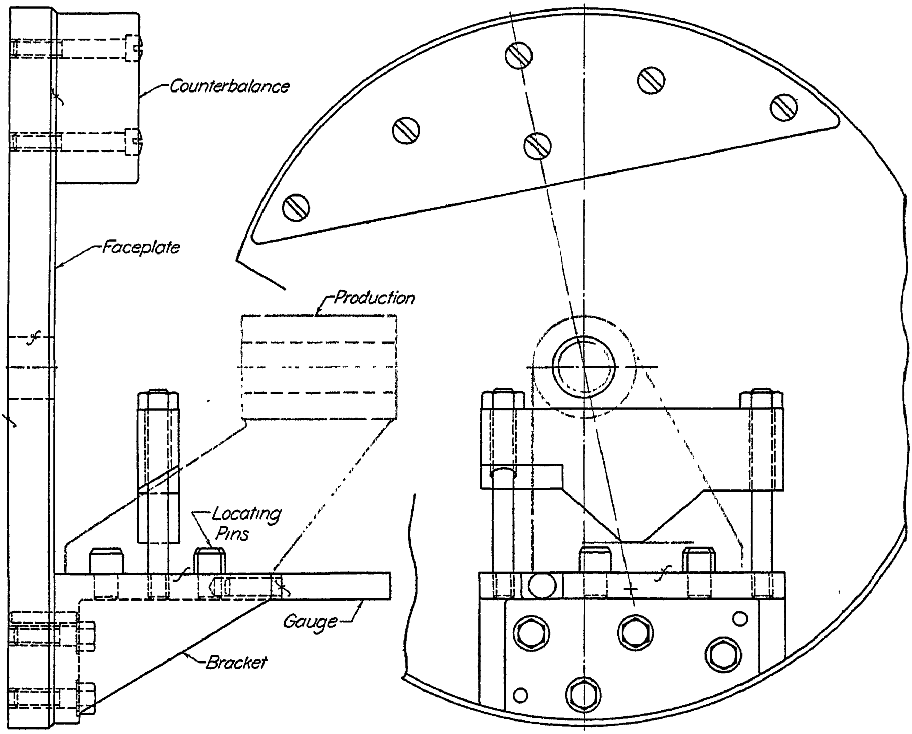


FIG. 735.—Counterbalanced boring and facing fixture.

To compute the size of the counterbalance the center of gravity and the moment of the fixture and production together about the working center must be found. From this the area and thickness of counterbalance and its working distance from the center may be calculated to find an equivalent moment to balance that on the opposite side of center. Common practice is to provide a slightly oversize counterbalance thickness, which allows the shop to complete the balance by removal of metal. This is a timesaver and permits slight changes that may take place in some parts used in the fixture.

In designing fixtures for milling, slotting, saw-cutting and similar operations the same principles of location and clamping as those given for jig designing are followed. To obtain secure clamping, finished bases should be provided with two square keys for aligning the fixture with the T-slots in the milling table, as well as with slots at each end for T-bolts.

If a previous operation has been performed on the subject, a gaging surface should be provided, if at all possible, to which the cutter may be set, thus obtaining accurately the required distance between the two finished surfaces.

PROBLEMS

298. The "tooling-up" procedure in machining a casting from its unfinished state to the finished product has an important bearing on the total cost and requires careful thought as to the proper sequence of operations. In the following problems consider the entire casting as rough, and prepare a shop procedure schedule, listing the tools in their successive order, so that each operation may have a direct relationship to the preceding one. Give the tools the progressive numbers *T*-1; *T*-2; etc.

1. Design a drill-and-ream jig for Fig. 447. Locate on a finished pad the lug in a finished slot and the finished end of the cylinder, 4″ long, against a finished boss of the jig. Clamp from the top and back with one setscrew each. Provide plain bushings for the base holes in the pad, and two liners with removable drill-and-ream bushings for the larger holes. Two lengths of removable bushings will be required, the longer being to reach into within a drill diameter of the cylinder 2¾″ long. Design a box-type body with feet opposite the sides in which bushings are placed. The right side of the body will be open to permit loading. Spot face the holes outside the jig.

2. Design a drill jig for special nut, Fig. 475. Locate over a center locator on a finished pad through the 1⅛″ hole, the locator reducing in size sufficiently to use a nut and C-washer for clamping on the 1¾″ diameter end. Nut should be small enough to clear the hole when loading and unloading. Provide bushings in an open-type body.

Alternative Method.—Use the same method of locating but provide only one drill bushing and an index pin 90 degrees from the bushing. Drill one hole, index this hole to the pin, drill the next hole, etc.

3. Design a drill-and-ream jig for the base segment, Fig. 467. The body may consist of two plates similar in shape to the production but longer, separated ⅝″ more than the thickness of the segment. This thickness may be taken as ½″. Locate against three pins, two being on the 19½″ radius and one at the left end, the pins being in the top plate and located in the jig at the time of locating the bushing holes on the jig borer.

Clamp in place against the pins and down to the finished surface upon which the segment rests. Provide the proper bushings in the top plate of the jig.

4. Fig. 593. Design a drill-and-ream jig for all holes in the centering-yoke base. Assume that the base and sides have been finished. Locate between finished surfaces of the jig, on a pad, and with the 4″ diameter base against a setscrew with lock nut. Clamp down to the pad and against the setscrew. Provide spring-backed pins or an equivalent means of holding the vertical sides of the casting against deflection upon application of the drilling pressure. Drill two holes for each slotting operation; all the remaining holes are to be drilled only, except the central base hole, which is to be reamed.

5. Fig. 599. Drill and ream the 1⅛″ hole, and drill for tapping the $\frac{7}{16}$-14NC-2 holes. Since the tops of the bosses have been finished before drilling, locate on them by means of two stationary V-blocks and a movable V-slide against the central cylinder. Use a bar clamp inside the 60-degree arms of the subject, placed approximately in the center of the triangle formed by the bosses.

6. Fig. 619. Design a drill-and-ream jig for the holes in the rocker arm, locating with V-blocks. The jig body will contain a bushing along the center line of the ⅜″ hole, which will make it necessary to provide feet on the side opposite the bushing.

7. Fig. 642. Design a drill jig for the ¼″ oilhole. Locate on a horizontal locator through the large center hole of the production, using a nut and C-washer for removal. Index the production with a pin through one of the cap-screw holes, so that the drill will enter the oil reservoir in the casting at the proper place.

8. Fig. 401. Design a boring-and-facing fixture for flange. Refer to the design shown in Fig. 734. Assume that the top flat surface has been finished and the ¾″ holes reamed prior to the operation of boring and facing in this fixture. For boring the 2⅝″ and 2″ diameter holes, use the two clamps, the center stud and washer being removed. For facing, remove or slip the clamps out of place and use the centering stud with washer and nut. On a production line, two fixtures could be made using those parts necessary for successive operations in each fixture.

9. Fig. 308. Design a boring-and-facing fixture for toggle-shaft bracket. Refer to the design shown in Fig. 735. Assume that the base is finished and the base holes reamed to size. Use these for locating over two pins, one flat and one round, and clamp down to the projecting shelf with a clamp as shown, or equivalent. This fixture should be counterbalanced to reduce vibration and obtain greater accuracy.

10. Design a drill-and-ream jig for the piece illustrated in one of the following figures: 607, 628, 646, 647, 665, 680.

CHAPTER XVIII

TECHNICAL SKETCHING

299. Facility in making a freehand orthographic drawing is an essential part of the equipment of every engineer. So necessary is this training in freehand sketching that it might almost be said that the preceding 17 chapters have all been in preparation for this one. Such routine men as tracers and detailers may get along with skill and speed in mechanical execution, but the designer must be able to *sketch* his ideas with a sure hand and clear judgment. In all inventive mechanical thinking, in all preliminary designing, in all explanation and instructions to draftsmen, freehand sketching is the mode of expression. Its mastery means the mastery of the language, and it is gained only after full proficiency in drawing with instruments is acquired. It is the mastery which the engineer, inventor, designer, chief draftsman and contractor, with all of whom time is too valuable to spend in mechanical execution, must have. It is the chief engineer's method of design.

The use and value of sketching are not confined to the engineering staff. A service man, for example, out on a trouble-giving machine may have to make a sketch, or a salesman in his daily report may need to send back sketches, perhaps of a customer's product, or even of some point of advantage in a competitor's machine.

Training in sketching develops accuracy of observation. It may be necessary to go a long distance frcm the drawing room to get some preliminary information, and the record thus obtained would be valueless if any detail were missing or obscure. Mistakes or omissions that would be discovered quickly in making an accurate scale drawing may easily be overlooked in a freehand sketch, and constant care must be exercised to prevent their occurrence.

Sometimes, if a piece is to be made but once, a sketch is used as a working drawing and afterward filed.

300. Kinds of Technical Sketches.—Sketches may be divided into two general classes: first, those made before the structure is built and, second, those made after the structure is built. In the first class are included the sketches made in connection with the designing of the structure, which may be classified as (*a*) *scheme* or *idea* sketches, used in studying and developing the arrangement and proportion of parts; (*b*) *computation sketches*, made in connection with the figured calculations for motion and strength; (*c*) *executive sketches*, made by the chief engineer, inventor or consulting engineer, to give instructions for special arrangements or ideas which must be embod-

ied in the design; (*d*) *design sketches*, used in working up the schemes and ideas into such form that the design drawing can be started; and (*e*) *working sketches*, made as substitutes for working drawings.

The second class includes (*a*) *detail sketches*, drawn from existing parts, with complete notes and dimensions, from which duplicate parts may be constructed directly, or from which working drawings may be made, Fig. 736; (*b*) *assembly sketches*, made from an assembled machine to show the relative positions of the various parts, with center and location dimensions, or sometimes for a simple machine, with complete dimensions and specifications; and (*c*) *outline* or *diagrammatic sketches*, generally made for the purpose of location; sometimes, for example, to give the size and location of pulleys and shafting, piping, or wiring, that is, information for use in connec-

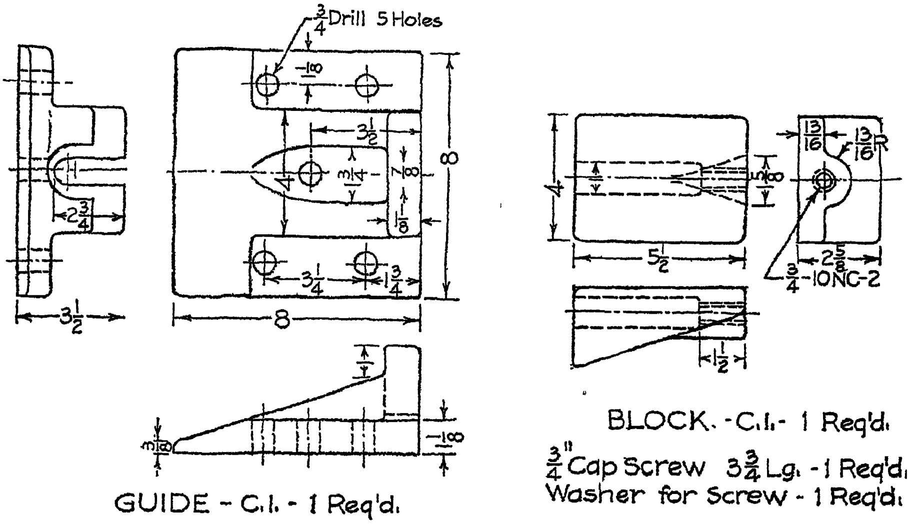


FIG. 736.—Detail sketch (leveling block).

tion with the setting up of machinery; sometimes to locate a single machine, giving the over-all dimensions, sizes and center distances for foundation bolts, and other necessary information.

301. Materials.—The only necessary materials for sketching are a pencil (F or H) sharpened to a long conical point, not too sharp, a pencil eraser, to be used sparingly, and paper—notebook, pad or single sheet clipped on a board.

In making working sketches from objects a 2-foot rule or flexible steel rule and calipers will be needed to obtain dimensions. Other machinists' tools may be required, such as a try square, surface gage, depth gage, thread gage and, for accurate measurements, a micrometer caliper. Sometimes a plumb line is of service. Much ingenuity is often required to get dimensions from an existing machine.

302. Technique.—The pencil should be held with freedom and not close to the point. Vertical lines are drawn downward with a finger movement

in a series of overlapping strokes, with the hand somewhat in the position of Fig. 737. Horizontal lines are drawn with the hand shifted to the position of Fig. 738, using a wrist motion for short lines and a forearm motion for longer ones. In drawing any straight line between two points, keep the eyes on the point to which the line is to go rather than on the point of the pencil. Do not try to draw the whole length of a line in a single stroke. It may be an aid to draw a *very* light line first, then to sketch the finished line,

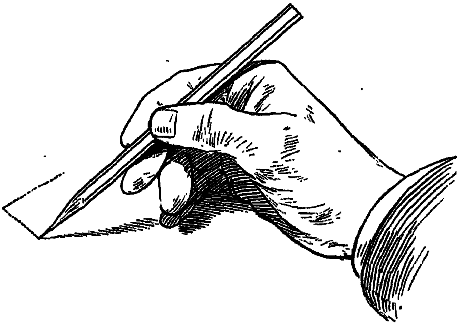


FIG. 737.—Sketching a vertical line.

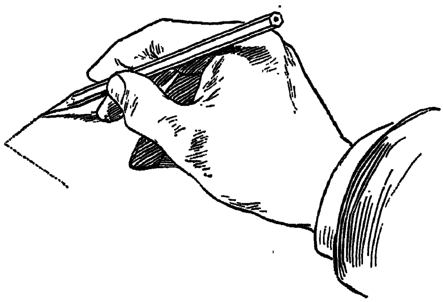


FIG. 738.—Sketching a horizontal line.

correcting the direction of the light line without rubbing it out. Do not be disturbed by any nervous waviness. Accuracy of direction is more important than smoothness of line.

It is legitimate in technical sketching to draw long vertical or horizontal lines by using the little finger as a guide along the edge of the pad or clip board.

Steep inclined lines running downward from right to left are drawn easily with the same movement as vertical lines, but those running downward

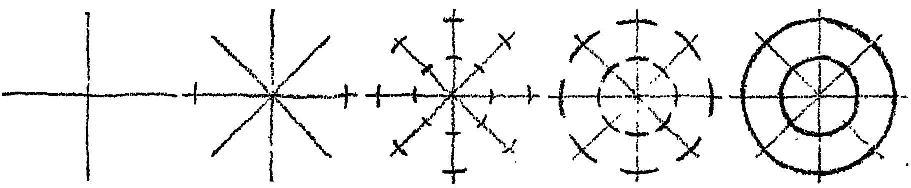


FIG. 739.—Method of sketching circles.

from left to right are much harder to draw (except for left-handed persons). They may be drawn by turning the paper and drawing them as horizontal lines. The three important things about a straight line are (1) that it be essentially straight, (2) that it be the right length and (3) that it go in the right direction.

Circles may be drawn by marking the radius on each side of the center lines, or, more accurately, by drawing two diagonals in addition to the center lines and marking points equidistant from the center on the eight

radii. At these points draw short arcs perpendicular to the radii, then complete the circle, as shown in Fig. 739. A modification is to use a slip of paper as a trammel. Large circles can be done very smoothly, after a little practice, by using the third or fourth finger as a pivot, holding the pencil stationary and rotating the paper under it, or by holding two pencils and using one as a pivot about which to rotate the paper. Another way of drawing a circle is to sketch it in its circumscribing square.

303. Practice.—The best preliminary training for this work of technical sketching is the drawing taught in the public schools, training as it does the hand and eye to see and represent form and proportion. Those who have not had this preparation should practice drawing lines with the pencil until the hand obeys the eye to a reasonable extent.

The best practice is obtained by sketching from castings, machine parts, or simple machines and making working drawings from those sketches, without further reference to the object. In classwork a variation may be introduced by exchanging the sketches so that the working drawing is made by another student. This will emphasize the necessity of putting down all the information and not relying on memory to supply what is missing. It is helpful to work with the idea that the object is not to be seen after the sketch is made. A most valuable training in observing details is sketching, from memory, a piece previously studied. It is an excellent training in sureness of touch to make sketches directly in ink, perhaps with a fountain pen.

304. Making a Sketch.—In making an orthographic sketch the principles of projection and the rules of practice for working drawings are to be remembered and applied. A systematic order should be followed for both idea sketches and sketches from objects, as listed below:

1. Visualize the object.
2. Determine the views.
3. Determine the size of the sketch.
4. Locate the center lines.
5. Block in the main outlines.
6. Complete the detail.
7. Add dimension lines and arrowheads.
8. Put on the dimensions.
9. Letter notes and title, with date.
10. Check the drawing.

Before a good graphical description of an object or idea can be developed it is essential that the mental image of it be definite and clear. The clearness of the sketch is a direct function of this mental picture. Hence the first step is to concentrate on visualization. This leads directly to the second step, determination of the necessary views and part views. These will probably not be just the same as would be made in a scale drawing. For example, a note in regard to thickness or shape of section will often be used to

save a view, Fig. 740; thus one view of a piece circular in cross section would be sufficient. In other cases additional part-views and extra sections may be sketched rather than complicate the regular views with added lines that might confuse the sketch, although the same lines might be perfectly clear in a measured drawing. The third step is to proportion the size of the sketch to the sheet. Have it large enough to show all detail clearly, but allow plenty of room for dimensions, notes and memoranda. Small parts may be sketched larger than full size. Do not try to crowd all the views on one sheet of paper. Use as many sheets as may be required, but name each view, indicating the direction in which it is taken. Sometimes one view alone will require a whole sheet.

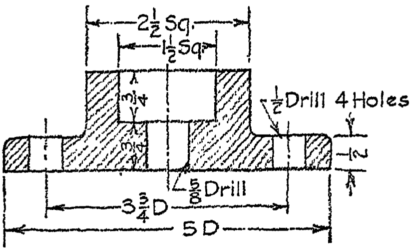


FIG. 740.—A one-view sketch.

In beginning a sketch, always start by locating the center lines or datum lines, and remember that the view showing the contour or characteristic shape should be drawn first. This is generally the view showing circles if there are any. Block in the main outlines, watching proportions carefully, selecting one edge as a unit from which to estimate the proportionate lengths of the other edges. When the main outlines are satisfactory, add the details, again watching proportions. One of the commonest faults in sketching is in getting details out of scale.

In drawing on plain paper, the location of the principal points, centers, etc., should be so marked that the sketches will fit the sheet, and the whole sketch, with as many views, sections and auxiliary views as are necessary to describe the piece, be drawn in as nearly correct proportion as the eye can determine, *without taking any measurements.*

A machine should, of course, be represented right side up, in its natural working position. If symmetrical about an axis, often one-half only need be sketched. If a whole view cannot be made on one page it may be put on two, each part being drawn up to a break line used as a datum line.

305. Dimension Lines.—After the sketching of a piece is finished it should be gone over, and dimension lines for all the dimensions needed for the construction added, drawing extension lines and arrowheads carefully and checking to see that none is omitted but still *making no measurements.*

306. Measuring and Dimensioning.—Up to this stage the object has not been handled, and consequently the drawing has been kept clean. The measurements for the dimensions indicated on the drawing may now be added. A 2-foot rule or steel scale will serve for getting most of the dimensions. Never used a draftsman's scale for measuring castings, as it will be soiled and have its edges marred. The diameter of cylindrical shapes or the distance between outside surfaces may be measured by using outside calipers and scale, Fig. 741, and the sizes of holes or internal surfaces, by using inside

calipers. Figure 742 illustrates the inside transfer caliper, used when a projecting portion prevents removing the ordinary caliper. The outside

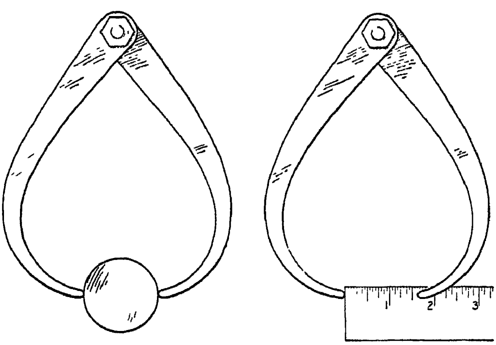


FIG. 741.—Outside caliper.

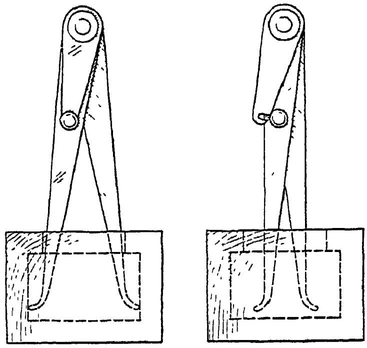


FIG. 742.—Inside transfer caliper.

transfer caliper is used for a similar condition, occurring with an outside measurement. The depth of a hole is easily measured with the depth gage, Fig. 743 *A*. Screw threads are measured by calipering the body diameter

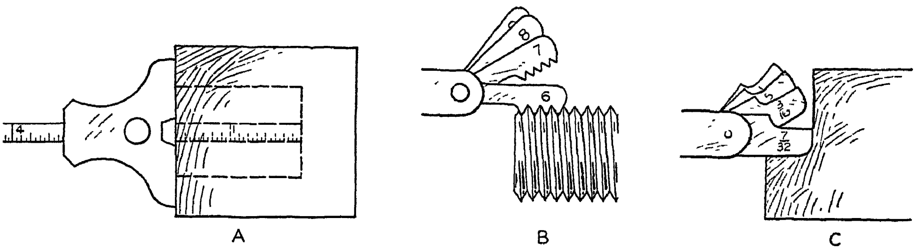


FIG. 743.—*A*, depth gage; *B*, screw-pitch gage; *C*, fillet and round gage.

and either counting the number of threads per inch or gaging with a screw-pitch gage, Fig. 743 *B*. A fillet-and-round gage measures radii by fitting the gage to the circular contour, Fig. 743 *C*. It is often necessary to lay a

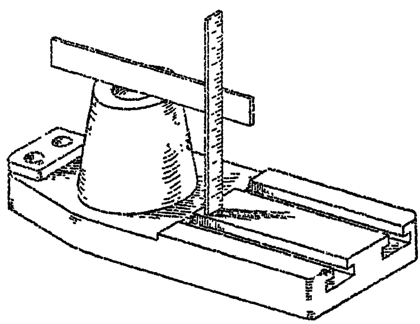


FIG. 744.—Taking a measurement.

straightedge across a surface as in Fig. 744. This type of measurement could be made conveniently with a combination square, or with a surface gage. The combination square uses two different heads, the regular 90°-45°

head, Fig. 745 *A*, for a variety of measurements, or the protractor head, Fig. 745 *B*, for measuring or laying out angles. For accurate measurements, outside or inside micrometer calipers are necessary. The outside type is illustrated in Fig. 746. Readings to 0.001″ are easily obtained. Accurate measurements of holes may be made with a telescopic gage in conjunction with an outside micrometer.

A variety of gages made for special purposes, as a wire gage, gage for sheet metal, etc., may be used as occasion demands. With some ingenuity, measurements can often be made with the simpler instruments when special ones are not available.

Always measure from finished surfaces, if possible. Judgment must be exercised in measuring rough castings so as not to record inequalities.

In finding the distance between centers of two holes of the same size, measure from the edge of one to the corresponding edge of the other. Curves are measured by coordinates or offsets, as shown in Fig. 465. A curved outline may be recorded by laying a sheet of paper on it and making a rubbing.

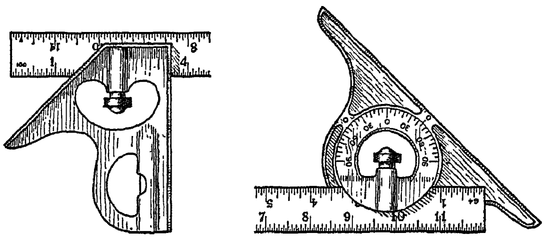


Fig. 745.—Combination square.

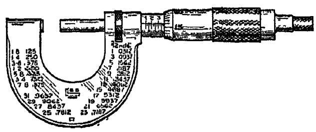


Fig. 746.—Outside micrometer caliper.

Add all remarks and notes that may seem to be of possible value.

The title should be written or lettered on the sketch, and for class sketches a statement of the amount of time spent on it.

Always Date a Sketch.—Valuable inventions have been lost through inability to prove priority, because the first sketches had not been dated. In commercial work the draftsman's notebook with sketches and calculations is preserved as a permanent record, and its sketches should be made so as to stand the test of time and be legible after the details of their making have been forgotten.

The final step is to check the sketch. It is a curious fact that when a beginner omits a dimension it is usually a basic, vital one, as that of the center height of a machine or the rise of an arch.

307. For gaining skill through practice, sketches should be made entirely freehand. However, in commercial work the engineer often saves time by making a hybrid sketch, drawing circles with the compasses, or even with a coin from his pocket, ruling some lines with a pocket scale or a triangle, and

making some freehand, but always keeping a workmanlike quality and good proportion.

Cross-section Paper.—Sketches are often made on coordinate paper ruled faintly in sixteenths, eighths, or quarters of an inch, used either simply as an aid in drawing straight lines and judging proportions, or for drawing to approximate scale by assigning suitable values to the unit spaces. The

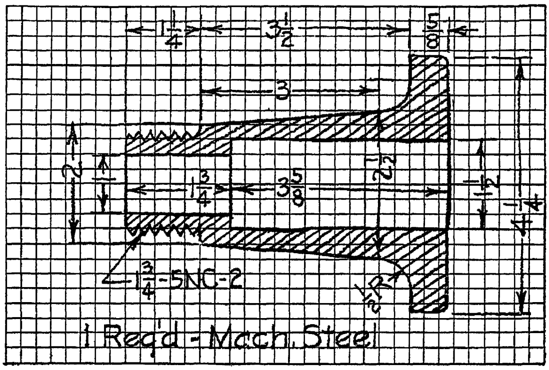


FIG. 747.—Sketch on coordinate paper.

latter use is more applicable to design sketches than to sketches from the object, Fig. 747.

PROBLEMS

308. Sketching problems may be made in great variety from pictorial views and from castings or models. The following are suggested:

Group I. Preliminary Line Practice.

1. Draw Fig. 50 to 53 without measurement in squares of about 6-inch sides.

Group II. Orthographic Sketches of Details.

2. Sketch the necessary orthographic views, without dimensions, of the pieces shown in Fig. 748.

3. Make orthographic sketches of selections from Figs. 245 to 286, adding the necessary dimensions according to the rules for dimensioning, paragraph 174.

4. From the assembly drawings, Figs. 637 to 654, select a single piece and make a detail sketch of it.

Group III. Sketches from Machine Parts.

5. Obtain a casting, forging or machined part such as a gear, pulley, etc., from the shop. Make a working sketch of the part selected.

Group IV. Sketches from Assembled Machines.

6. In the mechanical, industrial or electrical engineering laboratories, select an accessible part on one of the machines and make a working sketch.

Group V. Memory Sketching.

7. Look at one of the pieces of Fig. 748 with concentration for 15 seconds. Close the book and make its three views.

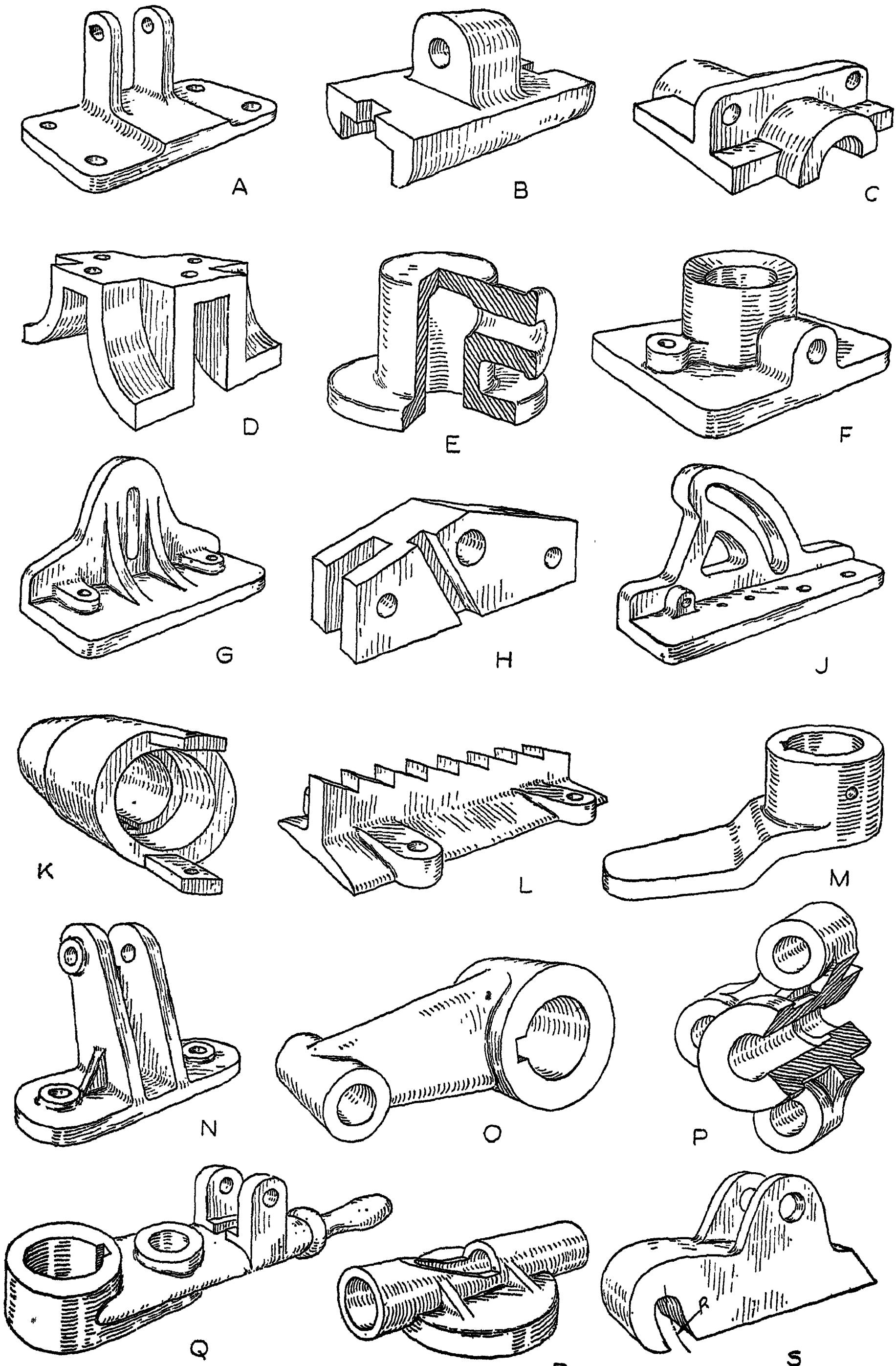


Fig. 748.—Problems for sketching.

CHAPTER XIX

DEVELOPED SURFACES AND INTERSECTIONS

309. Surfaces.—A surface may be considered to be generated by the motion of a line: the generatrix. Surfaces may thus be divided into two general classes: (1) those which can be generated by a moving *straight* line and (2) those which can be generated only by a moving *curved* line. The first are called *ruled surfaces;* the second, *double-curved surfaces.* Any position of the generatrix is called an *element* of the surface.

Ruled surfaces may be divided into (*a*) the *plane,* (*b*) *single-curved surfaces* and (*c*) *warped surfaces.*

The *plane* may be generated by a straight line moving so as to touch two other intersecting or parallel straight lines or a plane curve.

Single-curved surfaces have their elements either parallel or intersecting. In this class are the cylinder and the cone and also a third surface, which we shall not consider, known as the "convolute," in which consecutive elements intersect two and two.

Warped surfaces have no two consecutive elements either parallel or intersecting. There is a great variety of warped surfaces. The surface of a screw thread and that of the pilot of a locomotive are two examples.

Double-curved surfaces are generated by a curved line moving according to some law. The commonest forms are *surfaces of revolution,* made by revolving a curve about an axis in the same plane, as the sphere, torus or ring, ellipsoid, paraboloid, hyperboloid, etc. Illustrations of various surfaces may be found in Fig. 186.

310. Development.—In some kinds of construction, full-size patterns of some of the faces or of the entire surface of an object are required, as, for example, in stonecutting, a template or pattern giving the shape of an irregular face; or in sheet-metal work, a pattern to which a sheet may be cut so that when rolled, folded or formed it will make the object.

The complete surface laid out in a plane is called the *development* of the surface.[1]

Surfaces about which a thin sheet of flexible material (as paper or tin) can be wrapped smoothly are said to be developable; these include objects made up of planes and single-curved surfaces only. Warped and double-curved surfaces are nondevelopable, and when patterns are required for their construction they can be made only by methods that are approximate, but,

[1] The full theoretical discussion of surfaces, their classification, properties, intersections and development may be found in any good descriptive geometry.

assisted by the ductility or pliability of the material, they give the required form. Thus, while a ball cannot be wrapped smoothly, a two piece pattern developed approximately and cut from leather may be stretched and sewed on in a smooth cover, or a flat disk of metal may be die-stamped, formed or spun to a hemispherical or other required shape.

We have learned the method of finding the true size of a plane surface by projecting it on an auxiliary plane. If the true size of all the plane faces of an object made of planes are found and joined in order at their common edges so that all faces lie in a common plane, the result will be the developed surface. Usually this may be done to the best advantage by finding the true length of the edges.

The development of a right cylinder is evidently a rectangle whose width is the altitude, and length the rectified circumference, Fig. 749; and the development of a right circular cone is a circular sector with a radius equal to

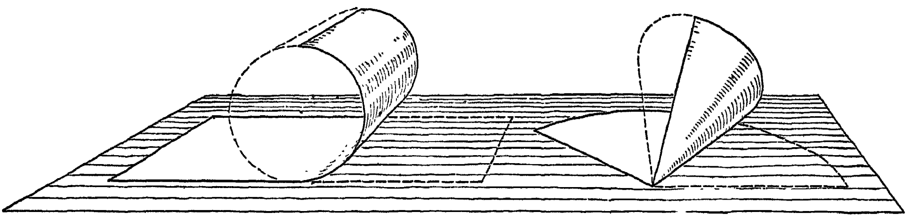


FIG. 749.—Development of cylinder and cone.

the slant height of the cone, and an arc equal in length to the circumference of its base, Fig. 749.

As illustrated in Fig. 749, developments are drawn with the inside face up. This is primarily the result of working to inside rather than outside dimensions of ducts. This procedure also facilitates the use of fold lines, identified by punch marks at either end, along which the metal is folded in forming the object.

In the laying out of real sheet-metal designs, an allowance must be made for seams and lap and, in heavy sheets, for the thickness and crowding of the metal; there is also the consideration of the commercial sizes of material, as well as the question of economy in cutting, in all of which some practical shop knowledge is necessary. Figure 765 and paragraph 326 illustrate and explain the usage of some of the more common joints, although the developments in this chapter will be confined to the principles alone.

311. Prisms.—A prism is a polyhedron whose bases or ends are equal parallel polygons and whose lateral faces are parallelograms. A right prism is one whose lateral faces are rectangles; all others are called oblique prisms. The axis of a prism is a straight line connecting the centers of the bases. A truncated prism is that portion of a prism lying between one of its bases and a plane which cuts all its lateral edges.

312. To Develop a Truncated Hexagonal Prism.—Fig. 750. First draw the projections of the prism: (1) a normal view of a right section (a section or cut obtained by a plane perpendicular to the axis) and, (2) a normal view of the lateral edges. The base, *ABCDEF*, is a right section shown in true size in the bottom view. Lay off on line *AA* of the development the perimeter of the base. This line is called by sheet-metal workers the "stretchout" or "girth" line. At points *A*, *B*, *C*, etc., erect perpendiculars called "measuring lines" or "bend lines," representing the lateral edges along which the pattern is folded to form the prism. Lay off on each of these its length *A*1, *B*2, *C*3, etc., as given on the front view. Connect the points 1, 2, 3, etc., in succession, to complete the development of the lateral surfaces. Note on the pattern that the inside of the lateral faces is toward the observer. For the development of the entire surface in one piece, attach the true sizes of the upper end and the base as shown, finding the true size of the upper end by an auxiliary view as described in paragraph 122. For economy of solder or rivets and time it is customary to make the seam on the shortest edge or surface. In seaming along the intersection of surfaces whose dihedral angle is other than 90°, as in the case here, the lap seam lends itself to convenient assembling. The flat lock could be used if the seam were made on one of the lateral faces.

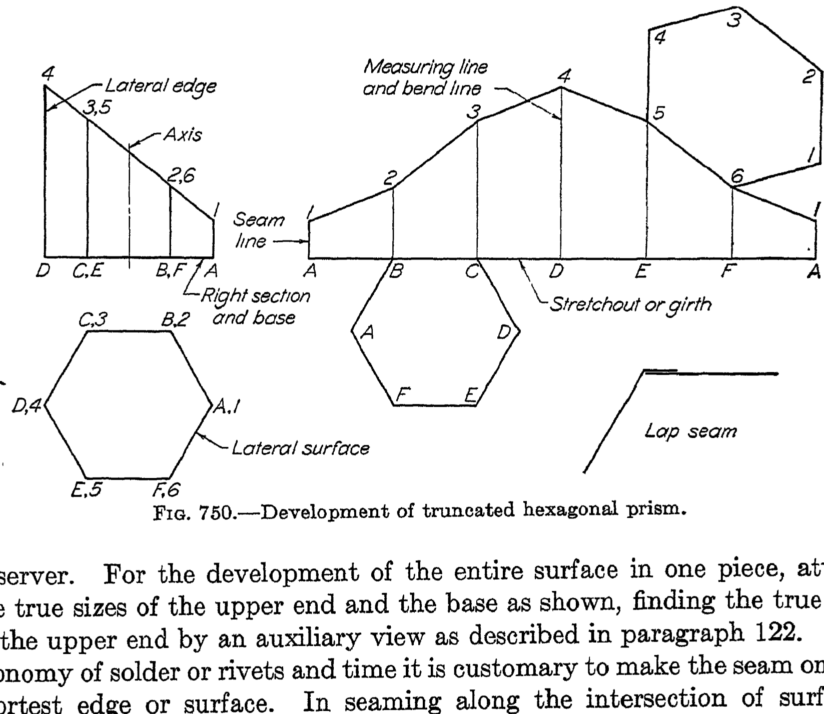


FIG. 750.—Development of truncated hexagonal prism.

313. Cylinders.—A cylinder is a single curved surface generated by the motion of a straight-line generatrix remaining parallel to itself and constantly intersecting a curved directrix. The various positions of the generatrix are elements of the surface. It is a right cylinder when the elements are perpendicular to the bases; an oblique cylinder when they are not. A truncated cylinder is that portion which lies between one of its bases and a

cutting plane which cuts all the elements. The axis is the line joining the centers of the bases.

314. To Develop a Truncated Right Cylinder.—Fig. 751. The development of a cylinder is similar to the development of a prism. Draw the projections of the cylinder: (1) a normal view of a right section and, (2) a normal view of the elements. In rolling the cylinder out on a tangent plane, the base or right section, being perpendicular to the axis, will develop into a straight line. For convenience in drawing, divide the normal view of the base, here shown in the bottom view, into a number of equal parts by points that represent elements. These divisions should be spaced so that the chordal distances closely enough approximate the arc to make the stretchout practically equal to the periphery of the base or right section. Project these elements up to the front view. Draw the stretchout and measuring

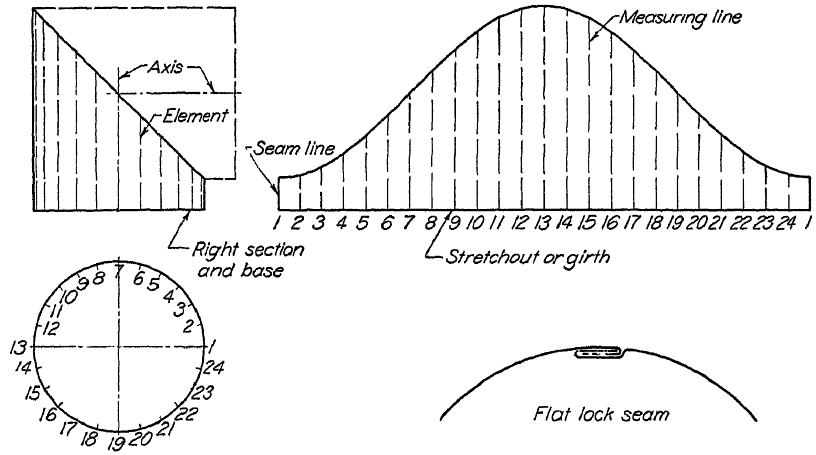


FIG. 751.—Development of truncated right cylinder.

lines as in Fig. 750, the cylinder now being treated as a many-sided prism. Transfer the lengths of the elements in order, either by projection or with dividers, and join the points thus found by a smooth curve, sketching it in very lightly, freehand, before fitting the French curve to it. This development might be the pattern of one-half of a two-piece elbow. Three-piece, four-piece or five-piece elbows may be drawn similarly, as illustrated in Fig. 752. As the base is symmetrical, only one-half of it need be drawn. In these cases the intermediate pieces as *B*, *C* and *D* are developed on a stretchout line formed by laying off the perimeter of a right section. If the right section is taken through the middle of the piece the stretchout line becomes the center line of the development.

Evidently any elbow could be cut from a single sheet without waste if the seams were made alternately on the long and short sides. The flat lock seam is recommended for Figs. 751 and 752, although other types could be used.

The octagonal dome, Fig. 753, illustrates an application of the development of cylinders. Each piece is a portion of a cylinder. The elements are parallel to the base of the dome and show in their true lengths in the top

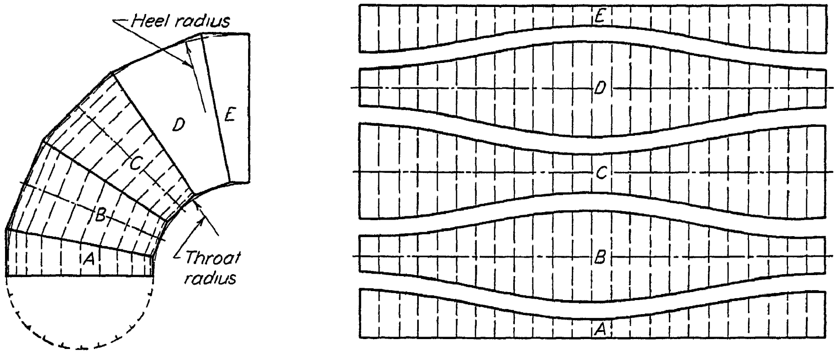


FIG. 752.—Development of five-piece elbow.

view. The true length of the stretchout line for sections A and A' shows in the front view at O_FH_F. By considering O_TH_T as the edge of a plane cutting a right section the problem is identical with the preceding problem.

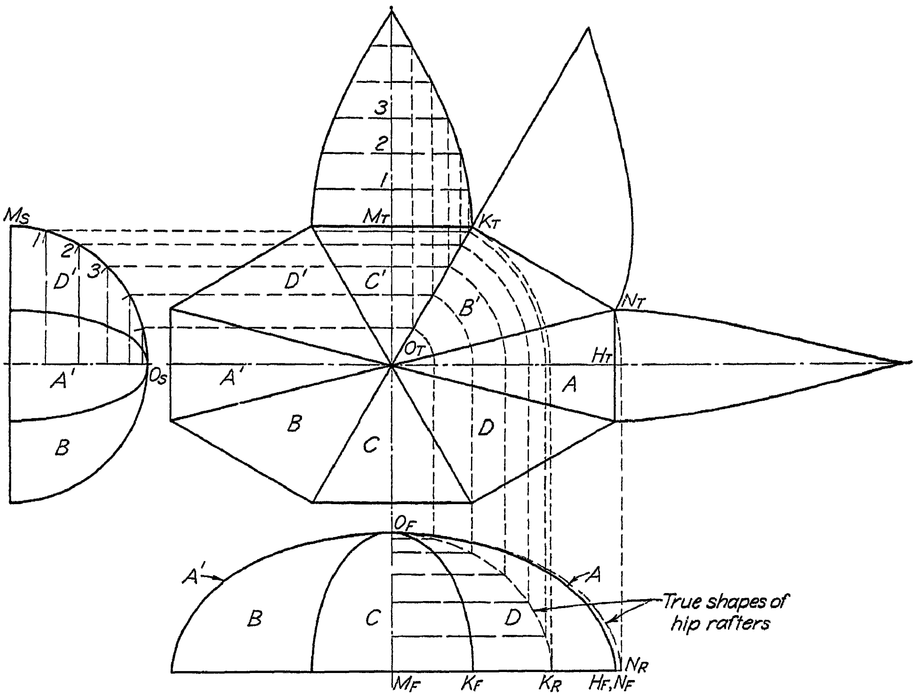


FIG. 753.—Development of octagonal dome.

Similarly the stretchout line for sections B, B', D and D' shows in true length at O_FK_R in the front view, and for section C and C' at O_SM_S in the side view.

The true shape of a hip rafter is found by revolving it until it is parallel to the frontal plane, in the same manner as in finding the true length of any line. A sufficient number of points should be taken to give a smooth curve.

315. Pyramids.—A pyramid is a polyhedron whose base is a polygonal plane and whose other surfaces are triangular planes meeting in a point called the "vertex." The axis is a line passing through the vertex and the mid-point of the base. The altitude is a perpendicular from the vertex to the base. A pyramid is *right* if the altitude coincides with the axis; it is *oblique* if they do not coincide. A truncated pyramid is that portion lying between the base and a cutting plane which cuts all the lateral edges. The frustum of a pyramid is that portion lying between the base and a parallel cutting plane cutting all the lateral edges.

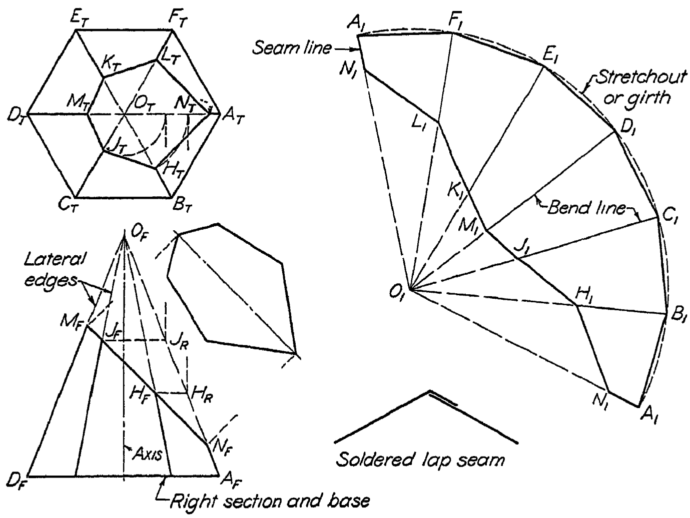


FIG. 754.—Development of truncated right hexagonal pyramid.

316. To Develop a Truncated Right Pyramid.—Fig. 754. Draw the projections of the pyramid which show (1) a normal view of the base or right section and (2) a normal view of the axis. Lay out the pattern for the pyramid and then superimpose the pattern of the truncation.

Since this is a portion of a right regular pyramid the lateral edges are all of equal length. The lateral edges OA and OD are parallel to the frontal plane and consequently show in their true length on the front view. With center O_1 taken at any convenient place and a radius O_FA_F, draw an arc which is the stretchout of the pattern. On it step off the six equal sides of the hexagonal base, obtained from the top view and connect these points successively with each other and with the vertex O_1, thus forming the pattern for the pyramid.

The intersection of the cutting plane and lateral surfaces is developed by laying off the true length of the intercept of each lateral edge on the corre-

sponding line of the development. The true length of each of these intercepts, such as OH, OJ, etc., is found by revolving it about the axis of the pyramid until they coincide with O_FA_F, as explained in paragraph 128. The path of any point, as H, will be projected on the front view as a horizontal line. To obtain the development of the entire surface of the truncated pyramid, attach the base; also find the true size of the cut face and attach it on a common line.

The lap seam is suggested for use here for the same reason that was advanced in paragraph 312.

The right rectangular pyramid, Fig. 755, is developed in a similar way, but as the edge OA is not parallel to the plane of projection it must be revolved to O_FA_R to obtain its true length.

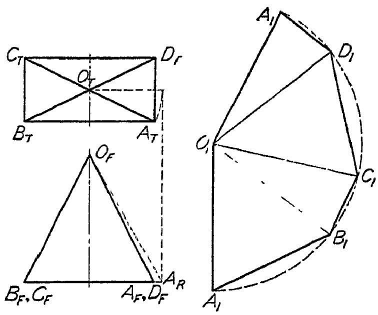


FIG. 755.—Development of right rectangular pyramid.

317. To Develop an Oblique Pyramid.—Fig. 756. Since the lateral edges are unequal in length, the true length of each must be found separately by revolving it parallel to the frontal plane as explained in paragraph 128. With O_1 taken at any convenient place, lay off the seam line O_1A_1 equal to O_FA_R. With A_1 as center and radius A_1B_1 equal to A_TB_T, describe an arc.

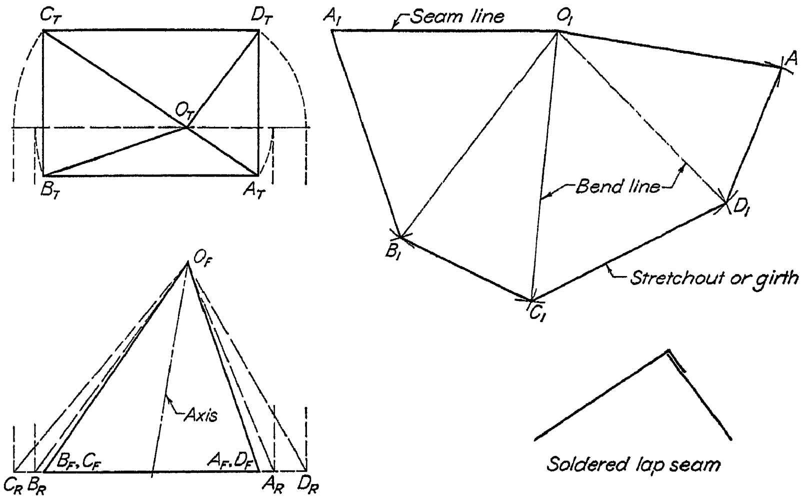


FIG. 756.—Development of oblique rectangular pyramid.

With O_1 as center and radius O_1B_1 equal to O_FB_R, describe a second arc intersecting the first in vertex B_1. Connect the vertices O_1, A_1, B_1, thus forming the pattern for the lateral surface OAB. Similarly lay out the patterns for the remaining three lateral surfaces, joining them on their common edges. The stretchout is equal to the summation of the base edges. If the complete development is required, attach the base on a com-

mon line. The lap seam is suggested as the most suitable for the given conditions.

318. Cones.—A cone is a single curved surface generated by the movement, along a curved directrix, of a straight-line generatrix, one point of which is fixed. The directrix is the base, and the fixed point the vertex of the cone. Each position of the generatrix is an element of the surface. The axis is a line connecting the vertex and the center of the base. The altitude is a perpendicular dropped from the vertex to the base. A cone is *right* if the axis and altitude coincide; it is *oblique* if they do not coincide. A truncated cone is that portion lying between the base and a cutting plane

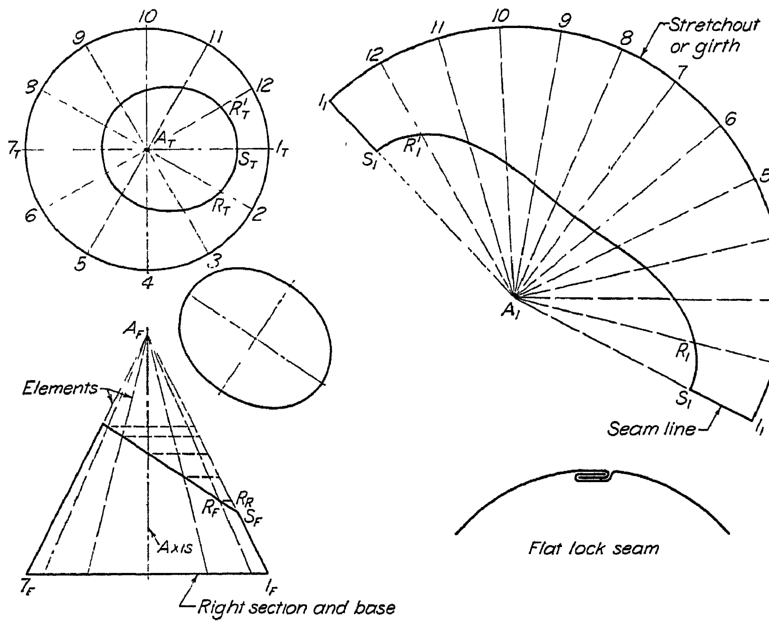


FIG. 757.—Development of truncated right circular cone.

which cuts all the elements. The frustum of a cone is that portion lying between the base and a parallel cutting plane which cuts all the elements.

319. To Develop a Truncated Right Circular Cone.—Fig. 757. Draw the projections of the cone which will show (1) a normal view of the base or right section and (2) a normal view of the axis. First develop the surface of the complete cone and then superimpose the pattern for the truncation.

Divide the top view of the base into a sufficient number of equal parts so that the sum of the resulting chordal distances will closely approximate the periphery of the base. Project these points to the front view and draw front views of the elements through them. With center A_1 and a radius equal to the slant height, A_F1_F, which is the true length of all the elements, draw an arc, which is the stretchout, and lay off on it the chordal divisions of the base, obtained from the top view. Connect these points 1_1, 2_1, 3_1,

etc., with A_1, thus forming the pattern for the cone. Find the true length of each element from vertex to cutting plane by revolving it to coincide with the contour element A_1, and lay off this distance on the corresponding line of the development. Draw a smooth curve through these points. The pattern for the cut surface is obtained from the auxiliary view. The flat lock seam is recommended here, although other types could be employed.

320. Triangulation.—Nondevelopable surfaces are developed approximately by assuming them to be made of narrow sections of developable surfaces. The commonest and best method for approximate development is that of triangulation, that is, the surface is assumed to be made up of a large number of triangular strips or plane triangles with very short bases. This method is used for all warped surfaces and also for oblique cones, which,

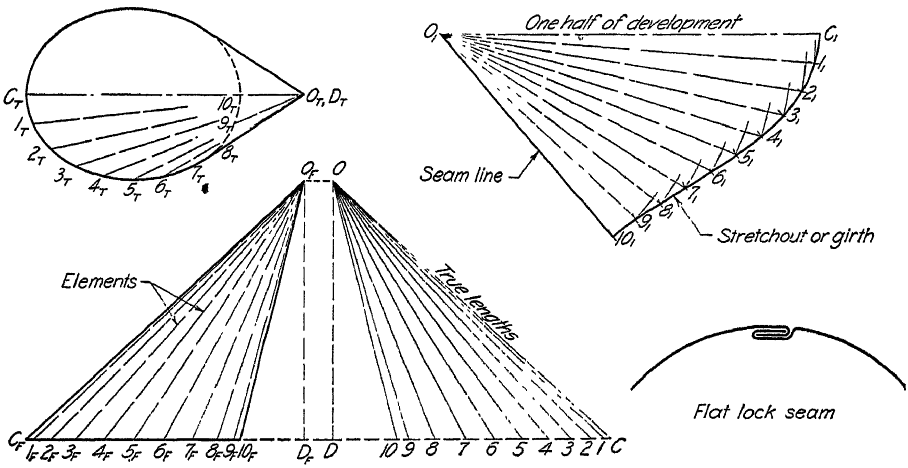


FIG. 758.—Development of oblique cone by triangulation.

although single-curved surfaces and capable of true theoretical development, can be developed much more easily and accurately by triangulation.

The principle is extremely simple. It consists merely in dividing the surface into triangles, finding the true lengths of the sides of each, and constructing them one at a time, joining these triangles on their common sides.

321. To Develop an Oblique Cone.—Fig. 758. An oblique cone differs from a cone of revolution in that the elements are all of different lengths. The development of the right circular cone is practically made up of a number of equal triangles meeting at the vertex, whose sides are elements and whose bases are the chords of short arcs of the base of the cone. In the oblique cone each triangle must be found separately.

If possible, draw views of the cone showing (1) a normal view of the base and (2) a normal view of the altitude. Divide the true size of the base, here shown in the top view, into a sufficient number of equal parts, so that the sum of the chordal distances will closely approximate the arc. Project

these points to the front view of the base. Through these points and the vertex draw the elements in each view. Since this cone is symmetrical about a frontal plane through the vertex the elements are shown only on the front half of it. Also, only one-half of the development is drawn. With the seam on the shortest element the element OC will be the center line of the development and may be drawn directly at O_1C_1, as its true length is given at O_FC_F. Find the true length of the elements by revolving them until parallel to the frontal plane, or by constructing a "true-length diagram." The true length of any element would be the hypotenuse of a triangle, one leg being the length of the projected element as seen in the top view, the other leg equal to the altitude of the cone. Thus, to make the diagram, draw the leg OD coinciding with or parallel to O_FD_F. At D and perpendicular

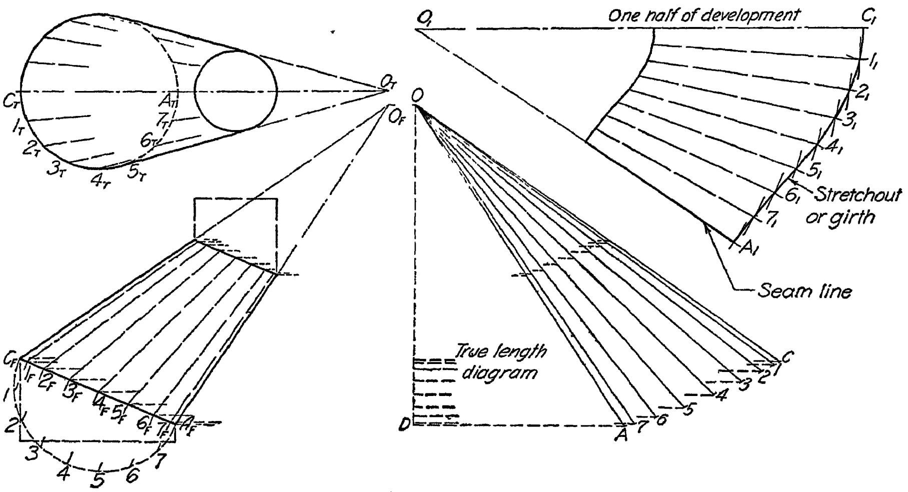


FIG. 759.—Development of a conical connection.

to OD draw the other leg, on which lay off the lengths $D1$, $D2$, etc., equal to D_T1_T, D_T2_T, etc., respectively. Distances from O to points on the base of the diagram are the true lengths of the elements.

Construct the pattern for the front half of the cone as follows: With O_1 as center and radius $O1$, draw an arc. With C_1 as center and radius C_T1_T, draw a second arc intersecting the first at 1_1; then O_11_1 will be the developed position of the element $O1$. With 1_1 as center and radius 1_T2_T, draw an arc intersecting a second arc with O_1 as center and radius $O2$, thus locating 2_1. Continue this procedure until all the elements have been transferred to the development. Connect the points C_1, 1_1, 2_1, etc., with a smooth curve, the stretchout line, to complete the development. The flat lock seam is recommended for joining the ends of the pattern to form the cone.

322. A conical connection between two parallel cylindrical pipes of different diameters is shown in Fig. 759. The method used in drawing the pattern is an application of the development of an oblique cone. One-half of

the elliptical base is shown in true size in an auxiliary view, here attached to the front view. Find the true size of the base from its major and minor axes; divide it into a number of equal parts so that the sum of these chordal distances closely approximates the periphery of the curve, and project these points to the front and top views. Draw the elements in each view through these points and find the vertex O by extending the contour elements until they intersect. The true length of each element is found by using the vertical distance between its ends as the vertical leg of the diagram and its horizontal projection as the other leg. As each true length from vertex to base is found, project the upper end of the intercept horizontally across from the front view to the true length of the corresponding element to find the true length of the intercept. The development is drawn by laying out each

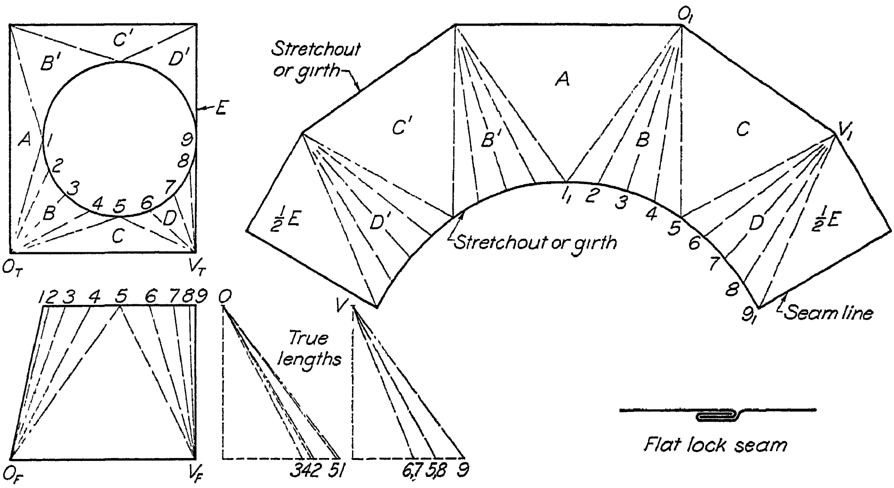


FIG. 760.—Development of a transition piece.

triangle in turn, from vertex to base as in paragraph 321, starting on the center line O_1C_1, then measuring on each element its intercept length. Draw smooth curves through these points to complete the pattern. Join the ends of the development with a flat lock seam to form the connection.

323. Transition pieces are used to connect pipes or openings of different shapes of cross section. Figure 760, showing a transition piece for connecting a round pipe and a rectangular pipe with parallel axes, is typical. These are always developed by triangulation. The piece shown in Fig. 760 is, evidently, made up of four triangular planes whose bases are the sides of the rectangle, and four parts of oblique cones whose common bases are arcs of the circle and whose vertices are at the corners of the rectangle. To develop it, make a true-length diagram as in Fig. 758. The true length of $O1$ being found, all the sides of triangle A will be known. Attach the development of cones B and B', then those of triangles C and C', and so on.

Figure 761 is another transition piece joining a rectangular to a circular pipe, whose axes are nonparallel. By using a partial right side view of the round opening, the divisions of the bases of the oblique cones can be found (as the object is symmetrical, one-half only of the opening need be divided). The true lengths of the elements are obtained as in Fig. 759.

With the seam line the center line of the plane E in Figs. 760 and 761, the flat lock is recommended for joining the ends of the development.

324. Triangulation of Warped Surfaces.—The approximate development of a warped surface is made by dividing it into a number of narrow quadrilaterals and then splitting each of these quadrilaterals into two triangles by a diagonal, which is assumed to be a straight line, although really a curve. Figure 762 shows a warped transition piece. Find the true size of one-half

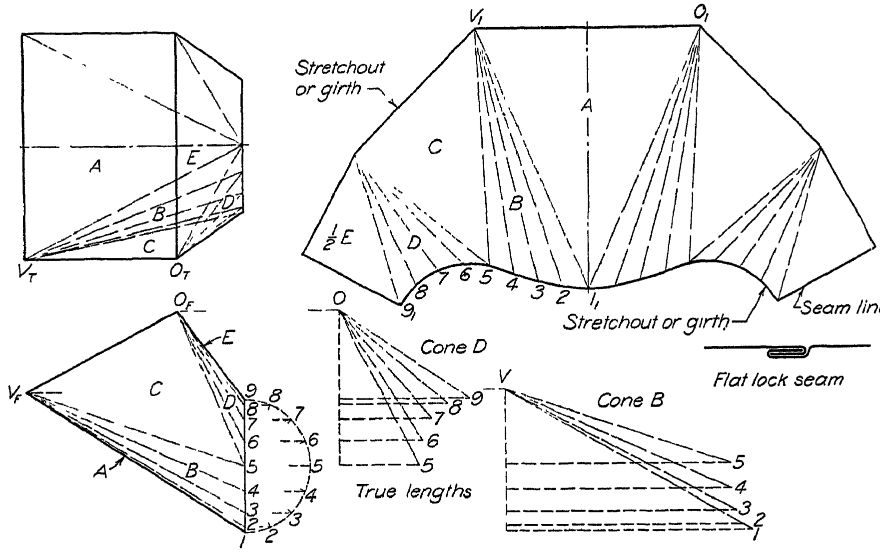


FIG. 761.—Development of a transition piece.

the elliptical base by revolving it, until horizontal, about an axis through 1, when its true shape will be seen on the top view. The major axis is 1, 7_R and the minor axis through 4_R equals 1, 7. Divide the semiellipse into a sufficient number of equal parts and project these to the top and front views. Divide the top semicircle into the same number of equal parts and connect similar points on each end, thus dividing the surface into approximate quadrilaterals. Cut each into two triangles by a diagonal. On true length diagrams find the lengths of the elements and the diagonals, and draw the development by constructing the true sizes of the triangles in regular order. The flat lock seam is recommended for joining the ends of the development.

325. To Develop a Sphere.—The sphere may be taken as typical of double-curved surfaces, which can be developed only approximately. It

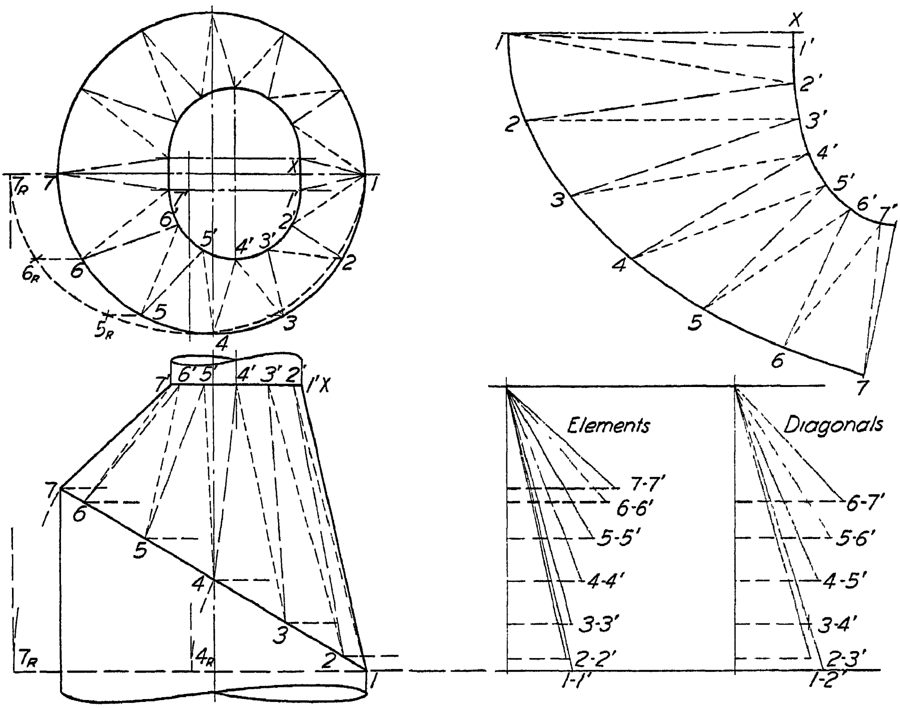


FIG. 762.—Development of a warped transition piece.

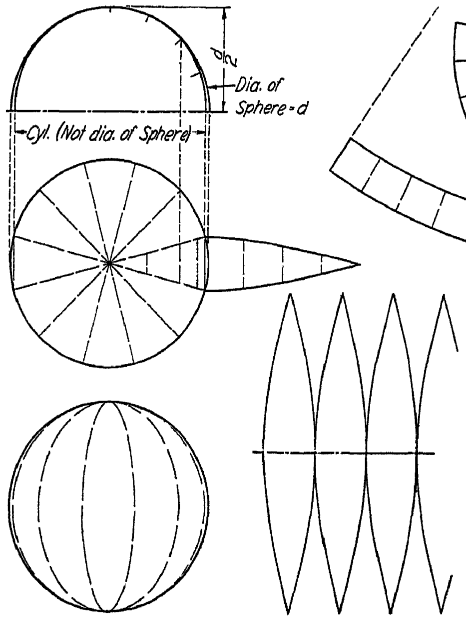


FIG. 763.—Sphere, gore method.

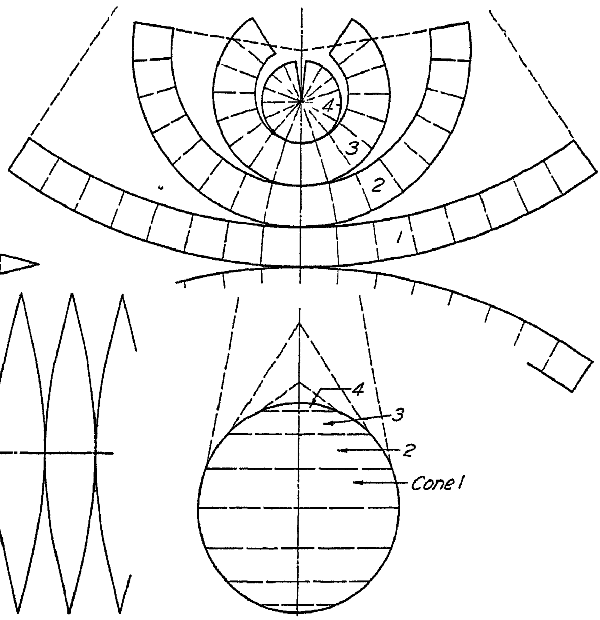


FIG. 764.—Sphere, zone method.

may be cut into a number of equal meridian sections or lunes as in Fig. 763, and these may be considered to be sections of cylinders. One of these sections developed as the cylinder in Fig. 763 will give a pattern for the others.

Another method is to cut the sphere into horizontal sections, or zones, each of which may be taken as the frustum of a cone whose vertex is at the intersection of the extended chords, Fig. 764.

326. Joints, Connectors and Hems.—There are numerous joints used in seaming sheet-metal ducts and in connecting one duct to another. Figure 765 illustrates some of the more common types, which may be formed by hand on a break, or by special seaming machines. No attempt to dimension the various seams and connections has been made here because of the variation in sizes for different gages of metal and in the forming machines of manufacturers.

The type of seam for longitudinal joints is selected according to conditions. For sheets from 20 to 28 gage, the flat lock seam is used more than

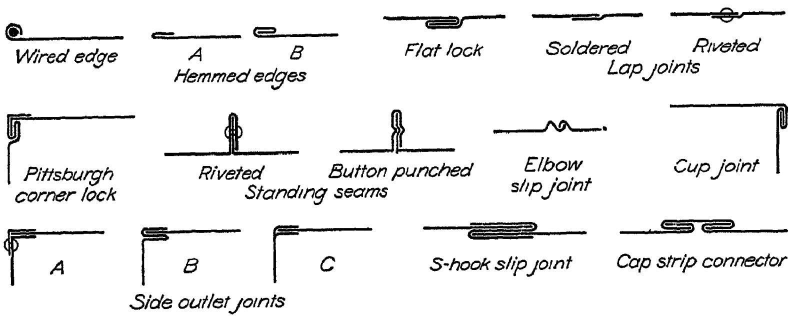


FIG. 765.—Cross-sections of joints and finished edges.

any other. The hammered or Pittsburgh lock is used more for irregular duct work, such as transformers, where one edge can be made straight for bending in the break or special forming machine. Lap joints are usually used where the application of the flat lock and hammered lock are not readily adaptable, such as metal heavier than 18 gage or corner joints other than 90 degrees.

For metals 18 gage and heavier, standing seams are generally employed for both longitudinal and cross seams. They serve the double purpose of seaming and stiffening large ducts.

The cap-strip or S-hook slip joints are used in connecting sections of prismatic ducts such as rectangular ones. The S-hook is usually used on temporary ducts or those that must be removed occasionally. The cap strip is used as a permanent connector.

For fastening side outlets to the main duct, connectors illustrated at A, B and C are used. Joints A and B are self-explanatory. At C the end of the side outlet is notched, and the resulting tabs are alternately lapped inside and outside the periphery of the hole in the main duct.

Hemming is used in finishing the raw edges of the end of the duct. In wire-hemming an extra allowance of about two and one-half times the diameter of the wire is made for wrapping around the wire. In flat hemming the end of the duct is bent over either once or twice to relieve the sharp edge of the metal.

327. The Intersection of Surfaces.—When two surfaces intersect, the line of intersection, which is the line common to both, may be thought of as a line in which all the elements of one surface pierce the other. Nearly every line on a drawing is a line of intersection, generally the intersection of two planes, or of a cylinder and a plane, giving a circle. The term "intersection of surfaces" refers, however, to the more complicated lines that occur when geometrical surfaces such as cylinders, cones, prisms, etc., intersect each other.

Two reasons make it necessary for the draftsman to be familiar with the methods of finding the intersections of surfaces: first, intersections are constantly occurring on working drawings and must be represented; second, in sheet-metal combinations the intersections must be found before the piece can be developed. In the first case it is necessary to find only a few critical points and "guess in" the curve; in the second case enough points must be determined to enable the development to be laid out accurately.

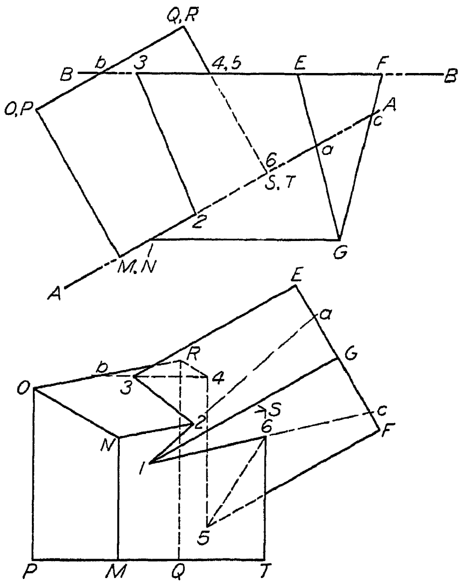


FIG. 766.—Intersection of two prisms.

Any practical problem resolves itself into some combination of the geometrical type forms. In general the method of finding the line of intersection of any two surfaces is to pass a series of planes through them in such a way that each plane cuts from each surface the simplest lines. The intersection of the lines cut from each surface by a plane will give one or more points on the line of intersection.

The following typical examples will illustrate the method of using cutting planes in finding the line of intersection of various combinations encountered in practical work.

328. To Find the Intersection of Two Prisms.—Fig. 766. In general, find the line of intersection of a surface on one prism with all surfaces on the other. Then take a surface adjacent to the first and find its intersections with the other prism. Continue in this manner until the complete line of intersection of the prisms is determined.

The method of locating end points on the line of intersection of two surfaces depends upon the position of the surfaces, as follows:

Both Surfaces Receding.—Their intersection appears as a point in the view in which they recede. Project the intersection to an adjacent view, locating the two ends of the intersection on the edges of one or both intersecting surfaces so that they will lie within the boundaries of the other surface. The intersection 4-5 of surfaces *QRST* and *EF*3 was obtained in this manner.

One Surface Receding, the Other Oblique.—An edge of the oblique surface may appear to pierce the receding surface in a view in which these conditions exist. If in an adjacent view the piercing point lies on the edge of the

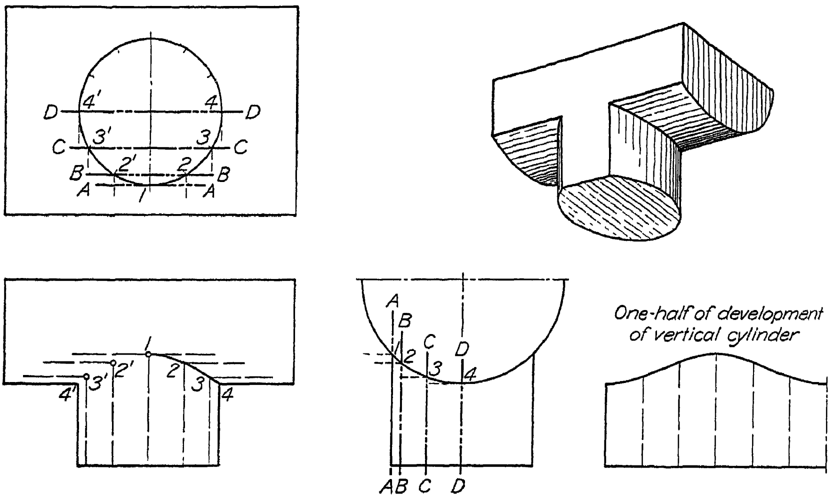


FIG. 767.—Intersection of two cylinders.

oblique surface and within the boundaries of the other surface, then it is an end point on the intersection of the surfaces. Point 5 lying on edge *F*5 of the oblique surface *FG*1-5 and the surface *QRST* is located in the top view in this manner. Point 1 was similarly established.

Both Surfaces Oblique.—Find the piercing point of an edge of one surface with the other surface, as follows: Pass a receding plane through an edge of one surface. Find the line of intersection of the receding plane and the other surface as explained above. The piercing point of the edge and surface is located where the line of intersection, just found, and the edge intersect. Repeat this operation to establish the other end of the line of intersection of the surfaces. Point 3, on the line of intersection 2-3 of the oblique surfaces *NORS* and *EG* 1-3, was found in this manner, by passing the receding plane *B-B* through edge *E*3; finding the intersection *b*4 of the surfaces and then locating point 3 at the intersection of *b*4 and *E*3.

329. To Find the Intersection of Two Cylinders.—Fig. 767. Cutting planes parallel to the axis of a cylinder will cut straight-line elements from

the cylinder. The frontal cutting planes A, B, C and D, parallel to the axis of each cylinder, cut elements from each cylinder, the intersections of which are points on the curve. The pictorial sketch shows a slice cut by a plane from the object, which has been treated as a solid in order to illustrate the method more easily. The development of the vertical cylinder is evident from the figure.

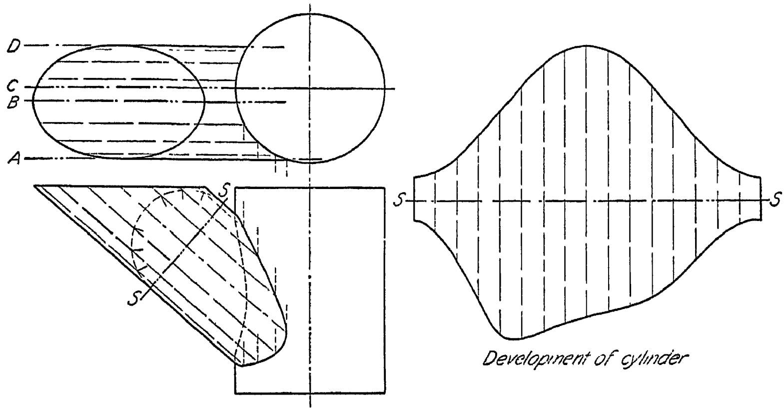


FIG. 768.—Intersection of two cylinders, axes not intersecting.

When the axes of the cylinders do not intersect, as in Fig. 768, the same method is used, but judgment must be exercised in the choice of cutting planes. Certain "critical planes" give the limits and turning points of the curve. Such planes should always be taken through the contour elements. For the position shown, planes A and D give the depth of the curve, the plane B the extreme height and the plane C the tangent or turning points on the contour element of the vertical cylinder. After the critical points have been determined a sufficient number of other cutting planes are used to give an accurate curve.

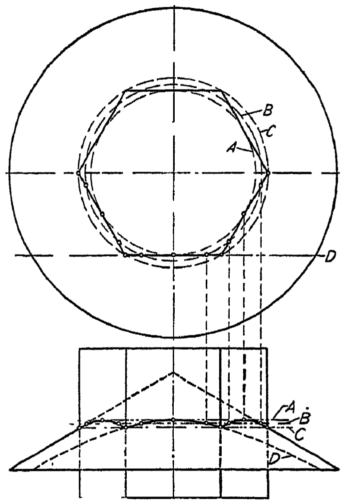


FIG. 769.—Prism and cone.

To develop the inclined cylinder a right section at S-S is taken, whose stretchout is a straight line equal in length to the circumference of the right section. If the cutting planes are taken at random the elements will not be spaced uniformly. To simplify the development, other planes may be assumed, by dividing the turned section into equal parts, as shown.

330. To Find the Intersection of a Prism and a Cone.—Fig. 769. In this case the choice of cutting planes parallel to H is made. Thus each plane cuts a circle from the cone and a hexagon from the prism, whose intersections

give points on the curve. The curve is limited between the plane A, cutting a circle whose diameter is equal to the short diameter of the hexagon, and the plane C, cutting a circle whose diameter is equal to the long diameter. As the prism is made up of six vertical planes the entire line of intersection of cone and prism consists of the ends of six hyperbolas, three of which are

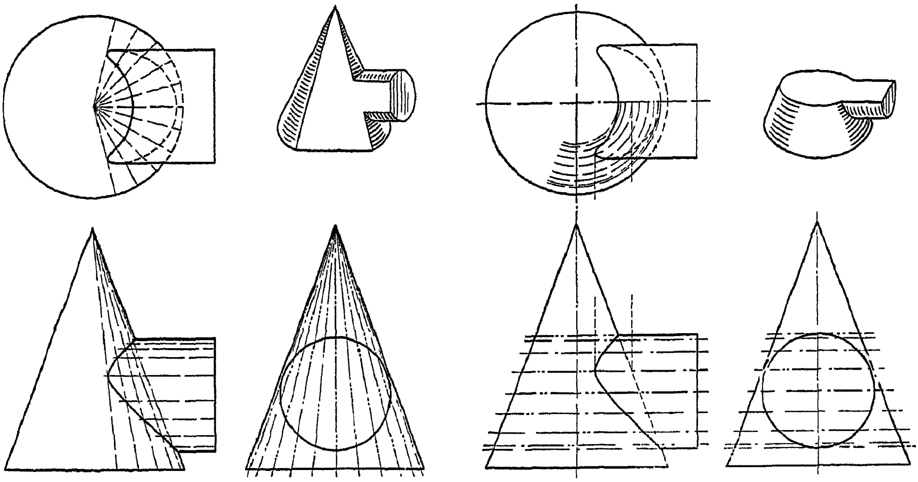


Fig. 770.—Intersection of cylinder and cone.

visible, one showing its true shape, as cut by plane D, the two others foreshortened. This figure illustrates the true curve in a chamfered hexagonal bolthead or nut. In practice it is always drawn approximately, with three circle arcs.

331. To Find the Intersection of a Cylinder and a Cone.—Fig. 770. Here the cutting planes may be taken so as to pass through the vertex of the

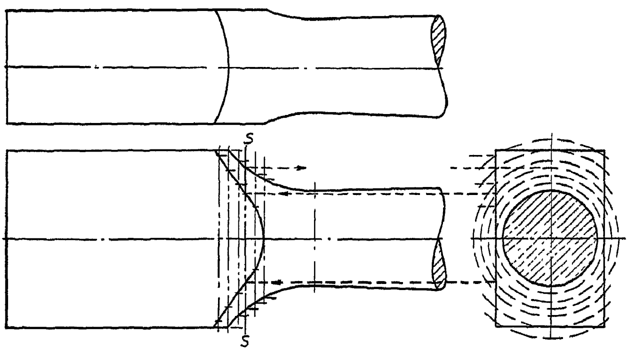


Fig. 771.—Intersection of a surface of revolution and a plane.

cone and parallel to the axis of the cylinder, thus cutting straight-line elements from both cylinder and cone; or, with a right circular cone, they may be taken parallel to the base so as to cut circles from the cone. Both systems of planes are illustrated in the figure. The pictorial sketches show

slices taken by each plane through the objects, which have been treated as solids in order to illustrate the method more easily. Some judgment is necessary in the selection of both the direction and the number of cutting planes. More points need to be found at the places of sudden curvature or changes of direction of the projections of the line of intersections.

332. To Find the Intersection of a Plane and a Surface of Revolution.—Fig. 771. This problem depends on the principle that planes perpendicular to the axis of any surface of revolution will cut circles (right sections). Thus the line of intersection of a plane and a surface of revolution is found by passing a series of planes perpendicular to the axis of revolution. Each of these planes will cut a straight line from the given plane and a circle from the surface of revolution, the intersection of which will give two points on the curve. In Fig. 771 the diameter of the circle cut by the plane *S-S* has been projected across to the end view and the points at which the circle cuts the "flat" projected back to *S-S* to give points on the curve.

PROBLEMS

333. Selections from the following problems may be made and the figures constructed accurately in pencil without inking. Any practical problem can be resolved into some combination of the "type solids," and the exercises given illustrate the principles involved in the various combinations.

An added interest in developments may be found by working the problems on suitable paper, allowing for fastenings and lap, and cutting them out. It is recommended that at least one or two models be constructed in this way.

In sheet-metal shops, development problems, unless very complicated, are usually laid out directly on the metal.

The following problems may be drawn on $8\frac{1}{2}'' \times 11''$ or $11' \times 17''$ sheets. Assume the objects to be made of thin metal with open ends unless otherwise specified.

Group I. Prisms.

1 to 6. Fig. 772. Develop lateral surfaces of the prisms.

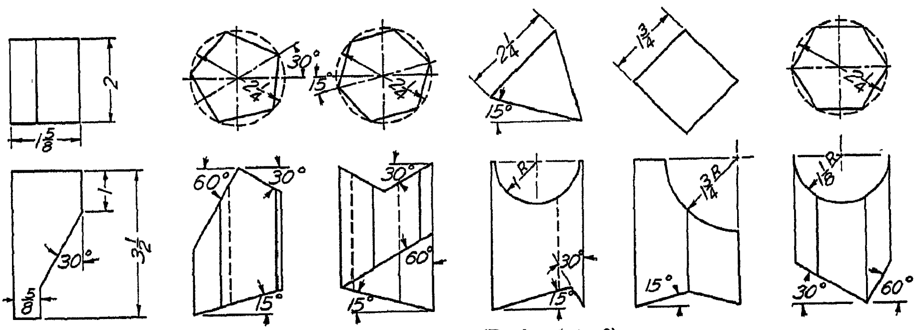


Fig. 772.—Prisms (Probs. 1 to 6).

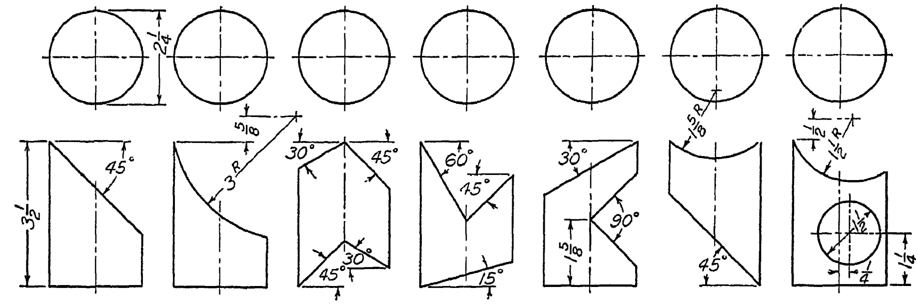


FIG. 773.—Cylinders (Probs. 7 to 13).

Group II. Cylinders.

7 to 13. Fig. 773. Develop lateral surfaces of the cylinders.

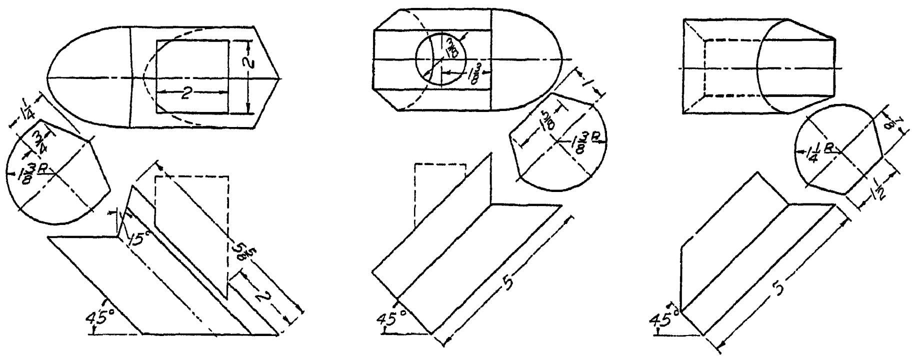


FIG. 774.—Combination surfaces (Probs. 14 to 16).

Group III. Combinations of Prisms and Cylinders.

14, 15, 16. Fig. 774. Develop lateral surfaces.

Group IV. Pyramids.

17, 18, 19, Fig. 775. Develop lateral surfaces of the hoppers.
20, 21. Fig. 775. Develop lateral surfaces of the pyramids.

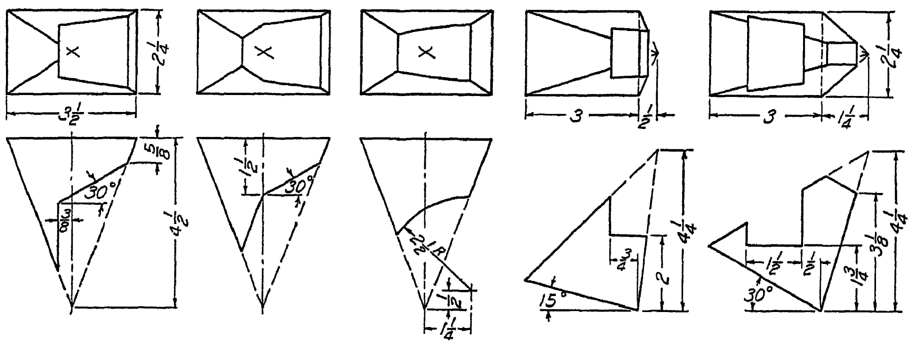


FIG. 775.—Pyramids (Probs. 17 to 21).

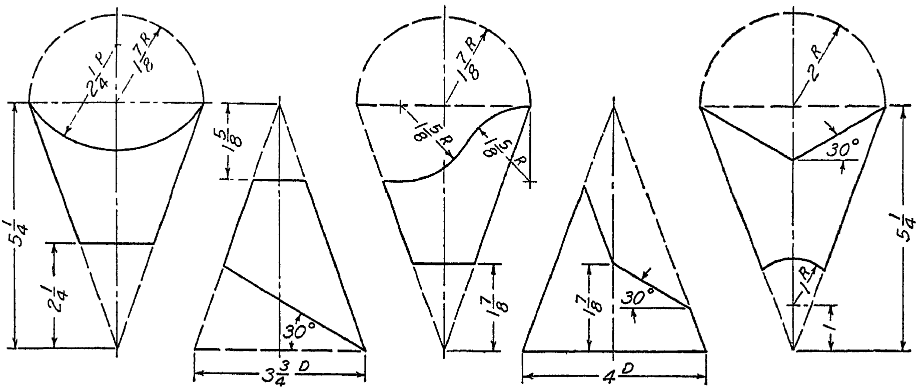


FIG. 776.—Cones (Probs. 22 to 26).

Group V. Cones.

22, 23, 24, 25, 26. Fig. 776. Develop lateral surfaces.

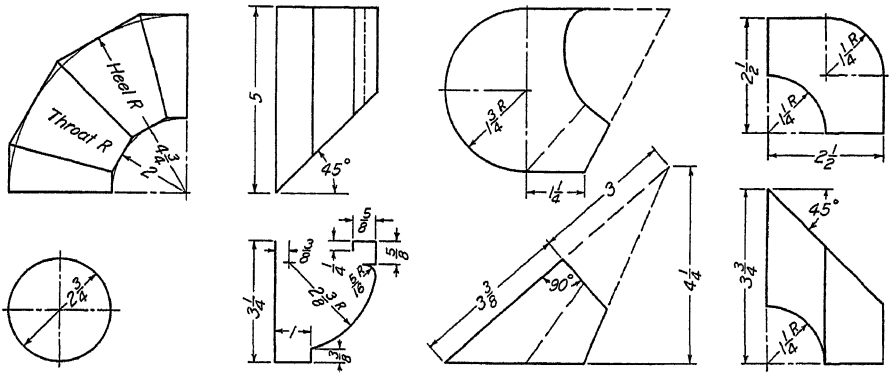


FIG. 777.—Various surfaces (Probs. 27 to 30).

Group VI. Developments.

27, 28, 29, 30. Fig. 777. Develop lateral surfaces of the objects. Note that 28 is a G.I. gutter, and 29 is a conical hood.

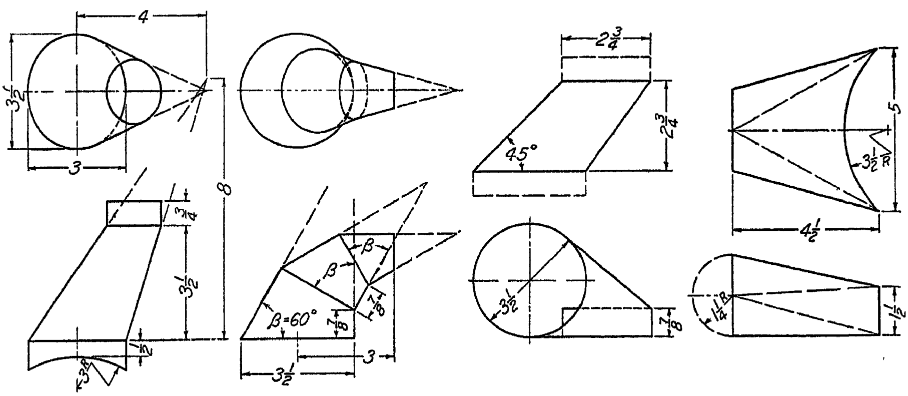


FIG. 778.—Transition pieces (Probs. 31 to 34).

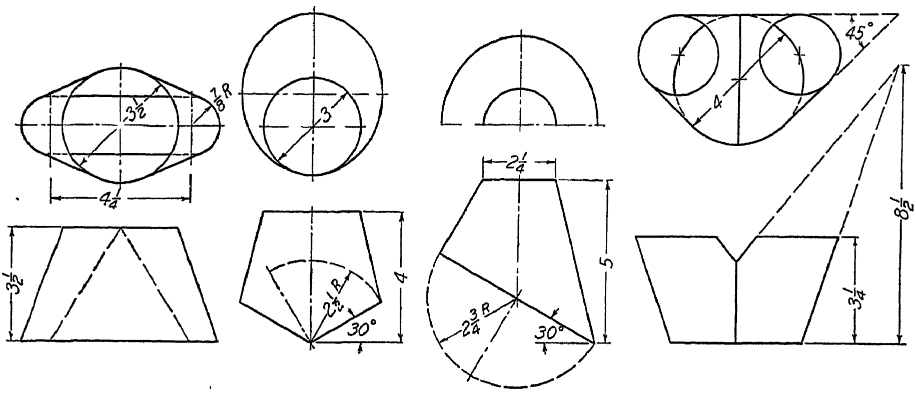


FIG. 779.—Transition pieces (Probs. 35 to 38).

Group VII. Cones and Transition Pieces.

31, 32, 33, 34, Fig. 778. Develop lateral surfaces of the objects (one-half of Probs. 31, 32, 34).

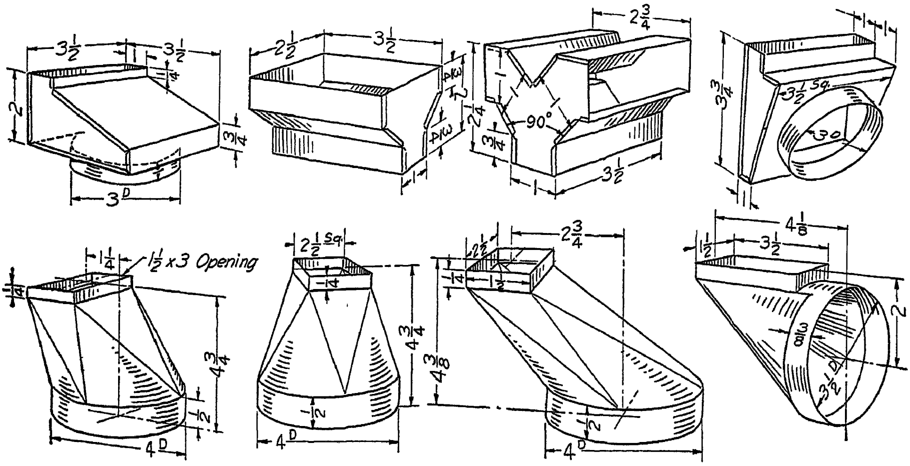


FIG. 780.—Sheet-metal connections (Probs. 39 to 46).

35, 36, 37. Fig. 779. Develop lateral surfaces of the objects (one-half).

38. Fig. 779. Develop surface of one-half of Y connection.

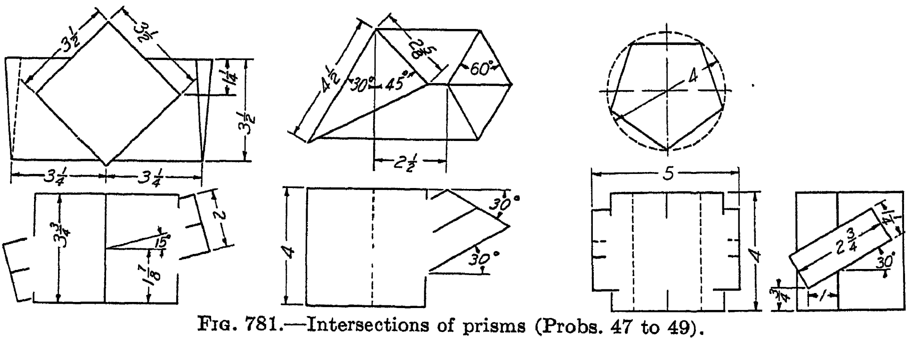


FIG. 781.—Intersections of prisms (Probs. 47 to 49).

Group VIII. Furnace-pipe Fittings.

39 to 46. Fig. 780. Develop surfaces and make paper models.

Group IX. Intersections of Prisms.

47, 48, 49. Fig. 781. Find line of intersection, considering prisms as pipes opening into each other. Use particular care in indicating visible and invisible portions of line of intersection. On another sheet develop the surfaces.

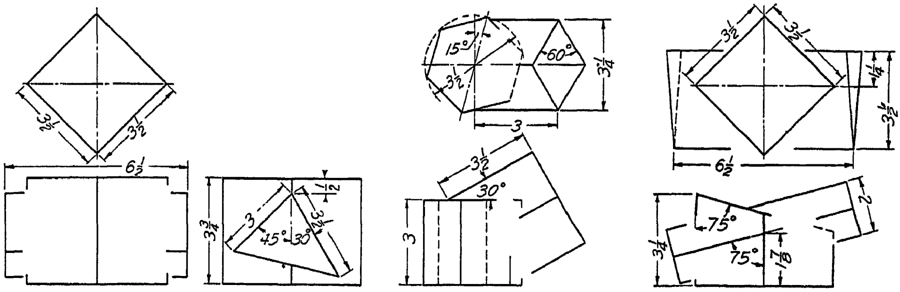


FIG. 782.—Intersections of prisms (Probs. 50 to 52).

50, 51, 52. Fig. 782. Find line of intersection, indicating visible and invisible parts, and considering prisms as pipes opening into each other. Note that in Probs. 51 and 52 the vertical pipes must have heads, cut out to fit inclined pipe.

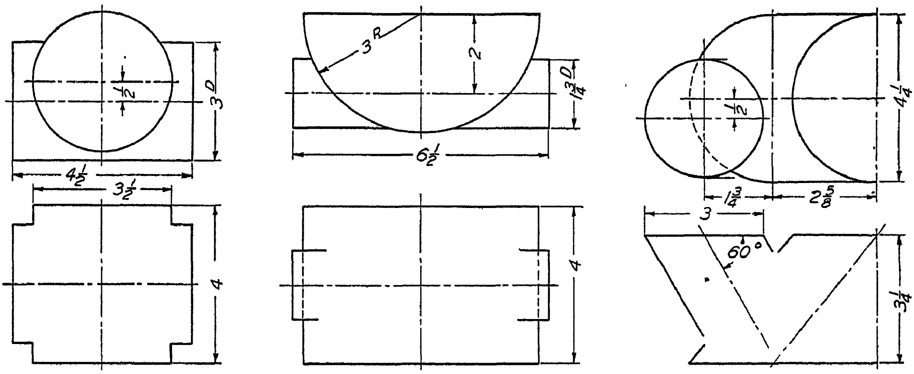


FIG. 783.—Intersections of cylinders (Probs. 53 to 55).

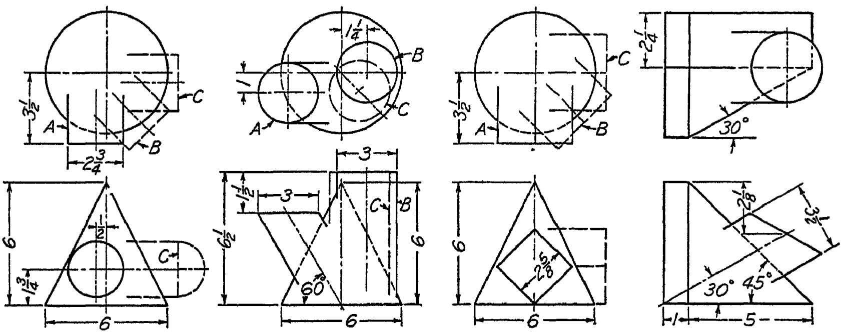


FIG. 784.—Intersections (Probs. 56 to 59)

Group X. Intersections of Cylinders.

53, 54, 55. Fig. 783. Find line of intersection, indicating visible and invisible portions and considering cylinders as pipes opening into each other. On another sheet develop the surfaces of each cylinder.

Group XI. Intersections of Surfaces.

56, 57, 58, 59. Fig. 784. Find lines of intersection.

60, 61, 62. Fig. 785. Find lines of intersection and develop surfaces.

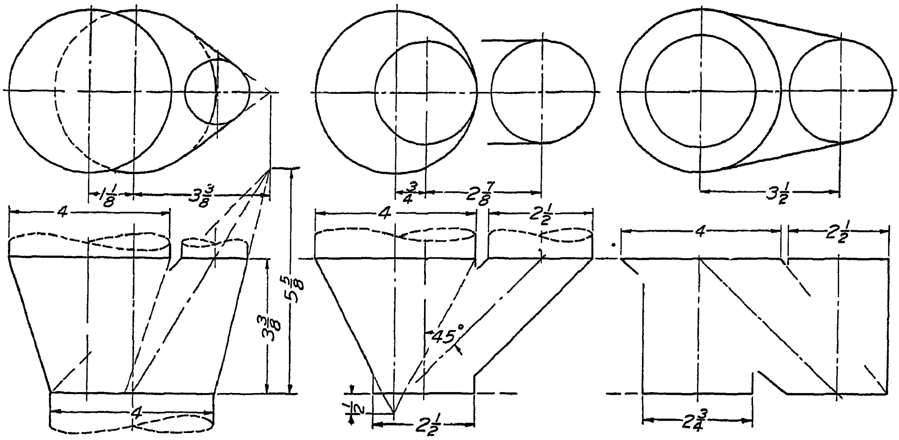


FIG. 785.—Intersections (Probs. 60 to 62).

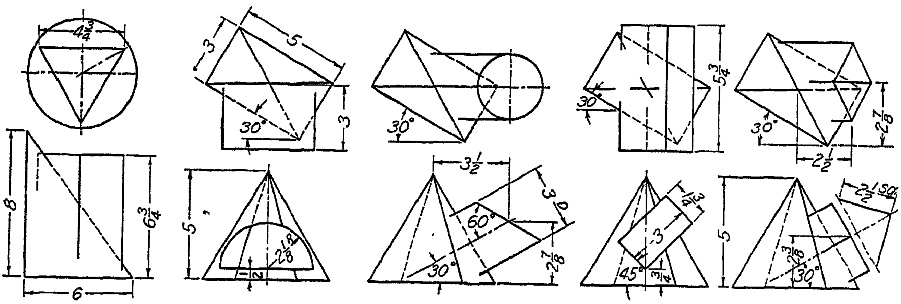


FIG. 786.—Intersections (Probs. 63 to 67).

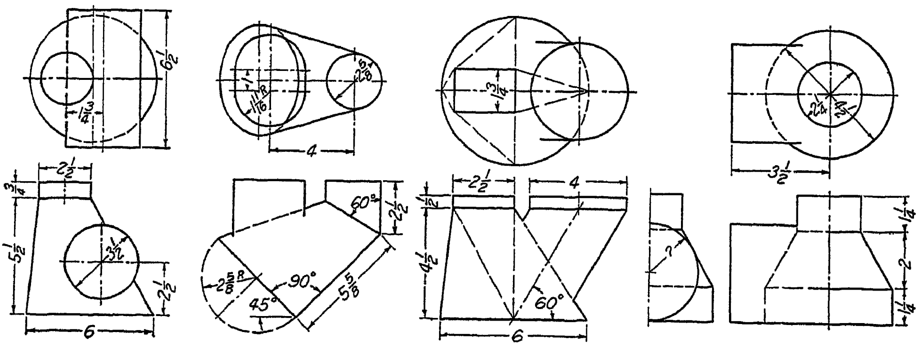


FIG. 787.—Intersections (Probs. 68 to 71).

63, 64, 65, 66, 67. Fig. 786. Find lines of intersection and develop surfaces.
68, 69, 70, 71. Fig. 787. Find lines of intersection and develop surfaces.

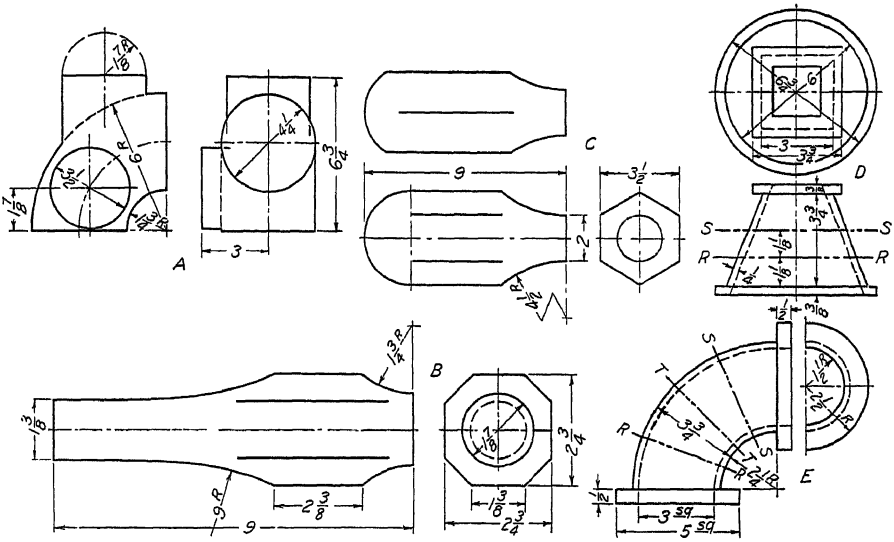


FIG. 788.—Surfaces cut by planes (Probs. 72 to 76).

Group XII. Surfaces Cut by Planes.

72, 73, 74, 75, 76. Fig. 788. Complete the views, finding lines of intersection. Make separate views of sections on planes indicated.

CHAPTER XX

PICTORIAL REPRESENTATION

334. In the study of the theory of projection in Chap. VI it was found that perspective projection shows the object as it appears to the eye but that its lines cannot be measured directly, while orthographic projection, with two or more views, shows it as it really is in form and dimensions but requires a trained imagination to visualize the object from the views. To combine the pictorial effect of perspective drawing with the possibility of measuring the principal lines directly, several forms of one-plane projection or conventional picture methods have been devised, in which the third dimension is taken care of by turning the object in such a way that three of its faces are visible. Along with the advantages of these methods go some serious disadvantages which limit their usefulness. The distorted effect is often unreal and unpleasant; only certain lines can be measured; the execution requires more time, particularly if curved lines occur, and it is difficult to add many figured dimensions; but even with their limitations a knowledge of these methods is extremely desirable as they can often be used to great advantage. Mechanical or structural details not clear in orthographic projection may be drawn pictorially or illustrated by supplementary pictorial views. Technical illustrations, patent-office drawings and the like are advantageously made in one-plane projection; layouts and piping plans may be drawn, as in Fig. 573, and many other applications will occur to draftsmen who can use these methods with facility. One of the most important reasons for learning them is that they are so useful in making freehand sketches, as already shown in Chap. VII.

335. Divisions.—Aside from perspective drawing, there are two general divisions of pictorial projection: first, *axonometric,* with its divisions into isometric, dimetric and trimetric; and, second, *oblique* projection, with several variations. Other methods not theoretically correct but effective are sometimes used.

336. Axonometric projection as shown in the tabular classification on page 87 is, theoretically, simply orthographic projection in which only one plane is used, the object being turned so that three faces show. Imagine a transparent vertical plane with a cube behind it, one face of the cube being parallel to the plane. The projection on the plane, that is, the front view of the cube, will be a square. Rotate the cube about a vertical axis through any angle less than 90°, and the front view will now show two faces, both foreshortened. From this position tilt the cube forward any amount less

than 90°. Three faces will now be visible on the front view. Thus there can be an infinite number of axonometric positions, only a few of which are ever used for drawing. The simplest of these is the *isometric* (equal-measure) position, in which the three faces are foreshortened equally. This is the basis for the isometric system.

337. Isometric Projection.—If a cube in position I, Fig. 789, is rotated about a vertical axis through 45° as shown in II, then tilted forward as in III until the edge AD is foreshortened equally with AB and AC, the front view of the cube in this position is said to be an "isometric projection" (the cube has been tilted forward until the body diagonal through A is perpendicular to the front plane. This makes the top face slope 35°16′ approx.)[1]

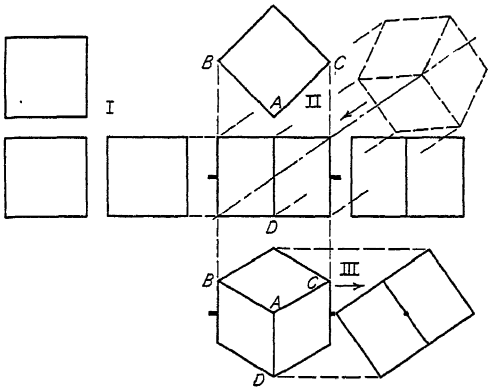


FIG. 789.—The isometric cube.

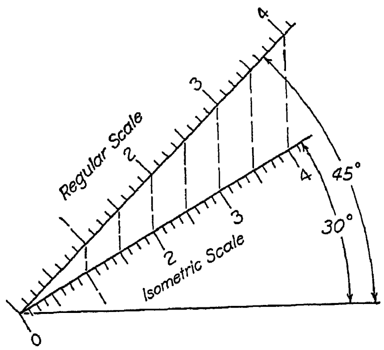


FIG. 790.—Isometric scale.

The projections of the three mutually perpendicular edges AB, AC and AD meeting at the front corner A make equal angles, 120°, with each other and are called *isometric axes*. Since the projections of parallel lines are parallel, the projections of the other edges of the cube will be respectively parallel to these axes. Any line parallel to an edge of the cube, and whose projection is thus parallel to an isometric axis, is called an *isometric line*. The planes of the faces of the cube and all planes parallel to them are called *isometric planes*.

In isometric projection the isometric lines have been foreshortened to approximately $^{81}/_{100}$ of their length, and an isometric scale to this proportion can be made graphically as shown in Fig. 790 if it becomes necessary to make an isometric projection to theoretical size.

338. Isometric Drawing.—In nearly all practical use of the isometric system this foreshortening of the lines is disregarded, and their full lengths

[1] In paragraph 127 the statement is made that the only difference between revolution and auxiliary projection is that in the former the object is moved and in the latter the plane is moved. Thus an auxiliary view on a plane perpendicular to a body diagonal of the cube in position II would be an isometric projection, as illustrated by the dotted view.

are laid off on the axes. This gives a figure of exactly the same shape but larger in the proportion of 1.23 to 1, linear, or, in optical effect 1.23^3 to 1.00^3, Fig. 791. Except when drawn beside the same piece in orthographic projection, the effect of increased size is usually of no consequence, and as the advantage of measuring the lines directly is of such great convenience, isometric drawing is used almost exclusively instead of isometric projection.

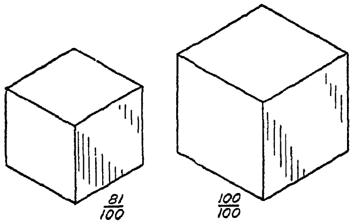


FIG. 791.—Isometric projection and isometric drawing.

339. To Make an Isometric Drawing. If the object is rectangular, start with a point representing a front corner and draw from it the three isometric axes 120° apart, one vertical, the other two with the 30° triangle, Fig. 792. On these three lines measure the height, width and depth of the object, as indicated; through the points so determined draw lines parallel to the axes, completing the figure. To draw intelligently in

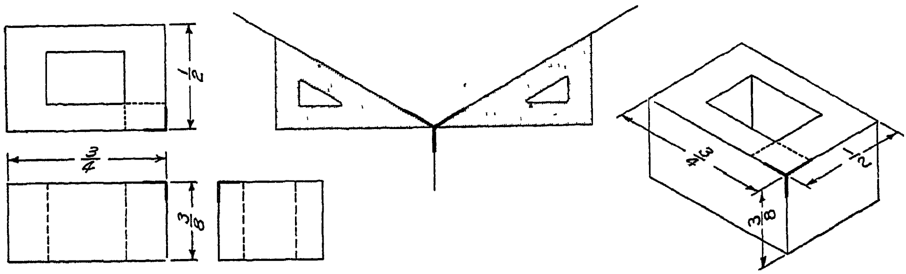


FIG. 792.—Isometric axes, first position.

isometric it is only necessary to remember the direction of the three principal isometric planes. Hidden lines are always omitted except when needed for the description of the piece.

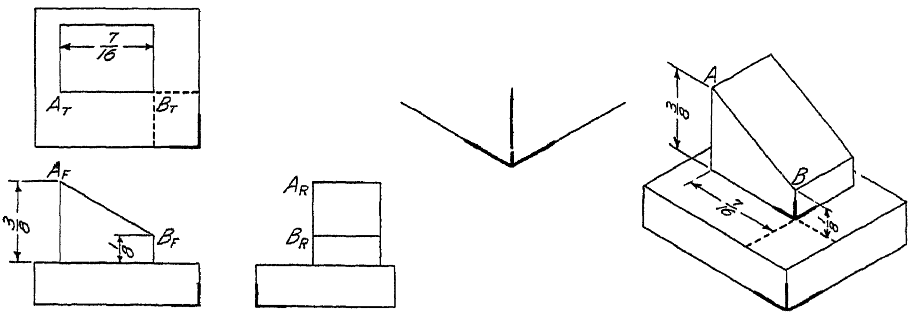


FIG. 793.—Isometric axes, second position.

It is often more convenient to build up an isometric drawing from the lower front corner, as illustrated in Fig. 793, starting from axes in what may be called the "second position."

Edges whose projections or drawings are not parallel to one of the isometric axes are called "nonisometric lines." The one important rule is: *measurements can be made only on the drawings of isometric lines;* and, conversely, measurements cannot be made on the drawings of nonisometric lines. For example, the diagonals of the face of a cube are nonisometric lines and, although equal in length, their isometric drawings will not be at all of equal length on the isometric drawing of the cube.

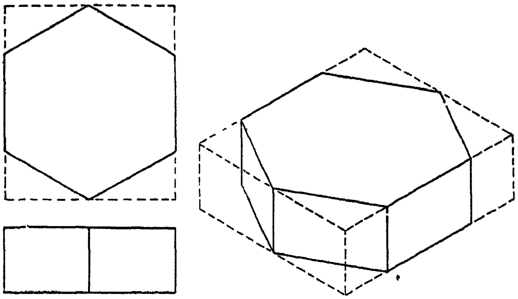


FIG. 794.—Box construction.

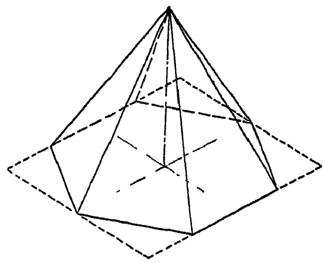


FIG. 795.—Semibox construction.

340. Objects Containing Nonisometric Lines.—Since a nonisometric line does not appear in the isometric drawing in its true length, the isometric view of each end of the line must be located and the isometric view of the line found by joining these two points. In Fig. 793, AB is a nonisometric line whose true length could not be measured on the isometric drawing.

When the object contains many nonisometric lines, it is drawn either by the "boxing method" or the "offset method." In the first method the

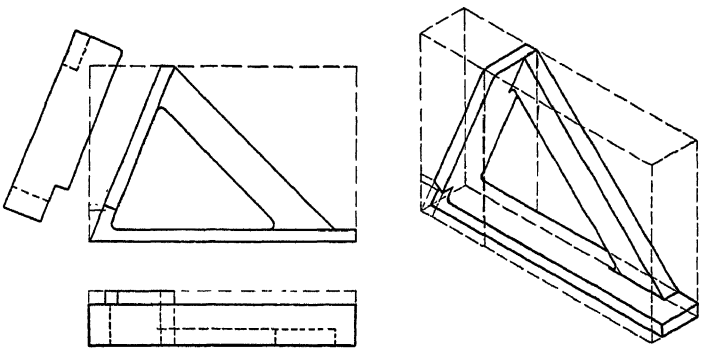


FIG. 796.—Box construction.

object is enclosed in a rectangular box, which is drawn around it in orthographic projection. The box is then drawn in isometric and the object located in it by its points of contact, as in Figs. 794 and 796. It should be noted that the isometric views of lines which are parallel on the object are parallel. Knowledge of this may often be used to save a large amount of construction, as well as to test for accuracy. Figure 794 might be drawn

by putting the top face into isometric and drawing vertical lines equal in length to the edges, downward from each corner. It is not always necessary actually to enclose the whole object in a rectangular "crate." The pyramid, Fig. 795, would have its base enclosed in a rectangle and the apex located by erecting a vertical axis from the center.

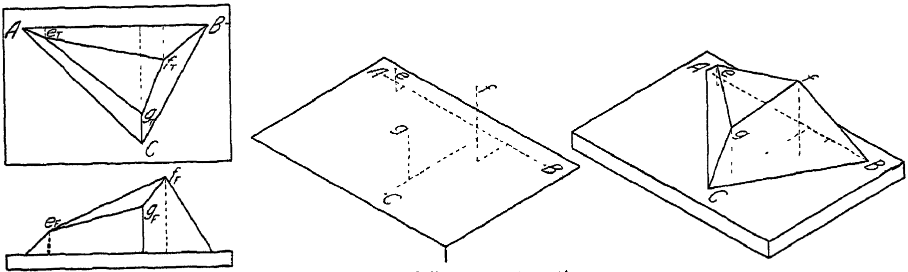


FIG. 797.—Offset construction.

The object shown in Fig. 796 is composed almost entirely of nonisometric lines. In such cases the isometric cannot be drawn without first making the orthographic views necessary for boxing. In general the boxing method is adapted to objects which have the nonisometric lines in isometric planes.

341. Offset Method.—When the object is made up of planes at a number of different angles it is better to locate the ends of the edges by the offset method. In this method, perpendiculars are dropped from each point to an isometric reference plane. These perpendiculars, which are isometric lines, are located on the drawing by isometric coordinates, the dimensions being

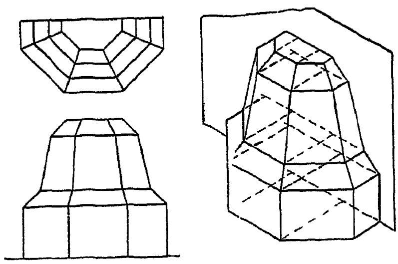


FIG. 798.—Offset construction

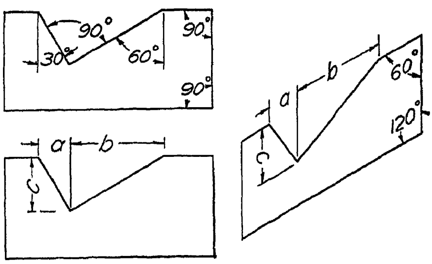


FIG. 799.—Angles in isometric.

taken from the orthographic views. In Fig. 797, line AB is used as a base line and measurements made from it as shown. Figure 798 is another example of offset construction, using a vertical plane as a reference plane.

Of course, angles in isometric drawing do not appear in their true sizes; thus it is necessary to locate the direction of the including sides by coordinates, as in Fig. 799. This is well illustrated also in Fig. 796.

342. Objects Containing Curved Lines.—It is obvious that a circle or any other curve on the face of a cube will not show in its true shape when the

cube is drawn in isometric. A circle on any isometric plane will be projected as an ellipse.

Any curve may be drawn by plotting points on it from isometric reference lines, as in Fig. 800. A circle plotted in this way is shown in Fig. 801.

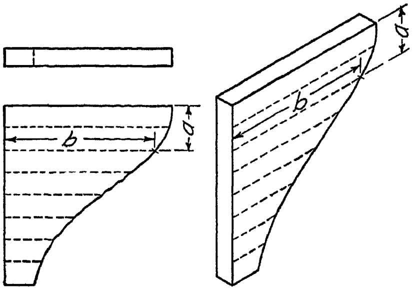


FIG. 800.—Curves in isometric.

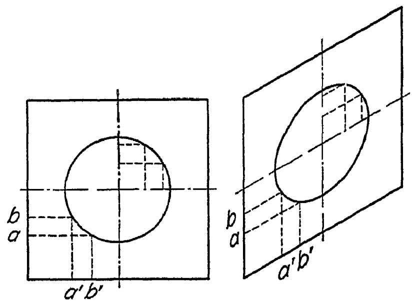


FIG. 801.—Circle, points plotted.

343. Isometric circles and circle arcs occur so frequently that they are usually drawn by a four-centered approximation, which is sufficiently accurate for all ordinary work. The center for any arc tangent to a straight

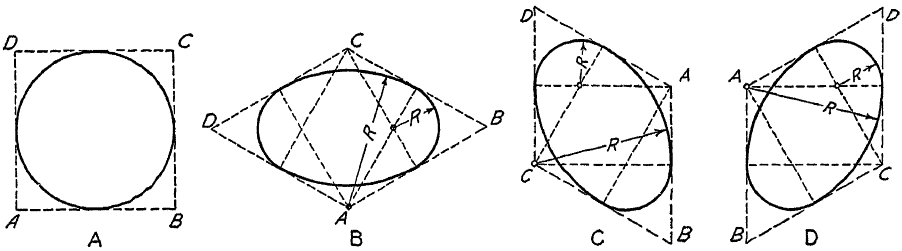


FIG. 802.—Isometric circle, four-center approximation.

line lies on a perpendicular from the point of tangency. If perpendiculars are drawn from the middle point of each side of the circumscribing square, the intersections of these perpendiculars will be centers for arcs tangent to two sides, Fig. 802*B*. Two of these intersections will evidently fall at the corners *A* and *C* of the square, as the perpendiculars are altitudes of equilateral triangles. The construction of Fig. 802*C* may thus be made by simply drawing 60° lines from the corners *A* and *C*.

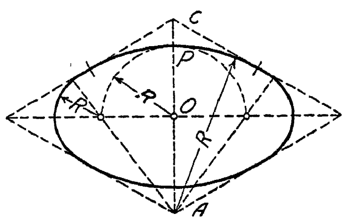


FIG. 803.—The Stevens method.

If a true ellipse is plotted in the same square as this four-centered approximation, it will be a little longer and narrower and of much more pleasing shape, but in the great majority of drawings the difference is not sufficient to warrant the extra expenditure of time required in execution. A little closer approximation may be made by the "Stevens method," a very simple four-centered method shown in Fig. 803. Draw the arcs from

A and *C* as before, extending them a little past the tangent point. With *O* as center and radius *OP* draw a semicircle intersecting the long diagonal in points which are to be used as centers for the end arcs.

344. Isometric Arcs.—To draw any circle arc, the isometric square of its diameter should be drawn in the plane of its face, with as much of the four-center construction as is necessary to find centers for the part of the

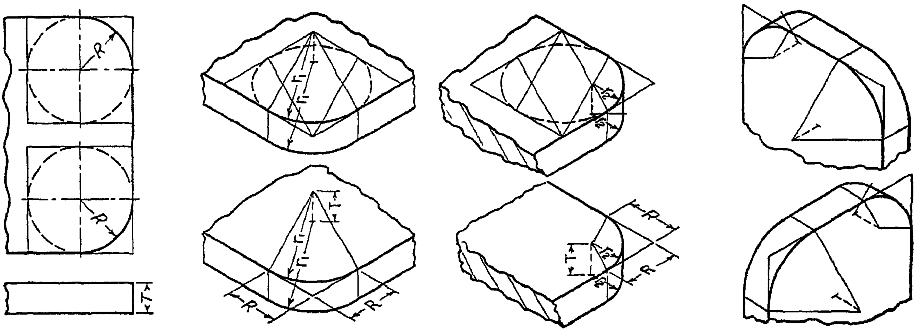


FIG. 804.—Isometric quarter circles (approximate method).

circle needed. The arc occurring most frequently is the quarter circle. Note that only two construction lines are needed to find the center of a quarter circle in an isometric plane. Figure 804 illustrates the method. Measure the true radius of the circle from the corner on the two isometric lines and draw actual perpendiculars from these points. Their intersection will be the required center for the isometric quadrant.

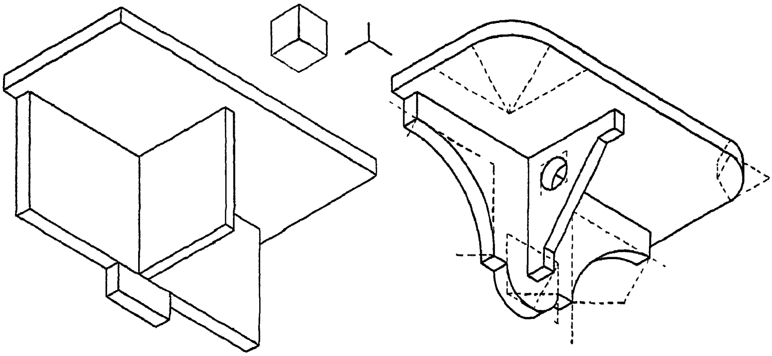


FIG. 805.—Construction with reversed axes.

The isometric drawing of a *sphere* is a circle with its diameter equal to the long axis of the ellipse inscribed in the isometric square of a great circle of the sphere. It would thus be 1.22/1.00 of the actual diameter (the isometric *projection* of a sphere would be a circle of the actual diameter of the sphere).

345. Reversed Isometric.—It is often desirable to show the lower face of an object by tilting it *back* instead of *forward,* thus reversing the usual

position so as to show the under side. The construction is just the same but the directions of the principal isometric planes must be kept clearly in mind. Figure 805 shows the reference cube and the position of the axes as well as the application of reversed-isometric construction to circle arcs.

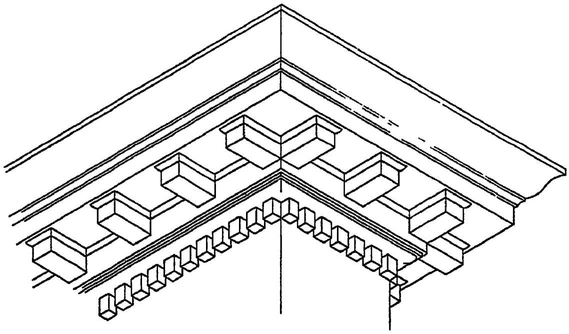


FIG. 806.—Architectural detail on reversed axes.

A practical use of this construction is in the representation of such architectural features as are naturally viewed from below. Figure 806 is an example.

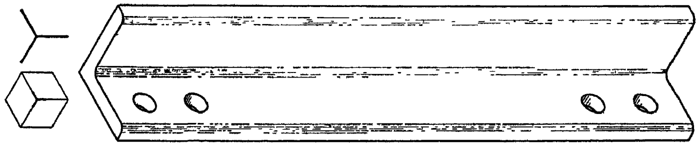


FIG. 807.—Isometric with main axis horizontal.

Sometimes a piece may be shown to better advantage with the main axis horizontal, as in Fig. 807.

346. Isometric Sections.—Isometric drawings are, from their pictorial nature, usually outside views, but sometimes a sectional view may be

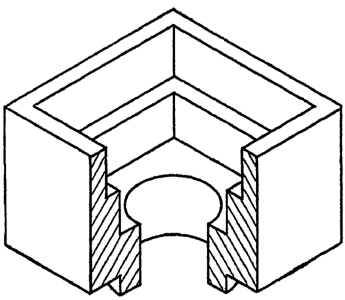


FIG. 808.—Isometric half section.

employed to good advantage to show a detail of shape or interior construction. The cutting planes are taken as isometric planes and the section lining is done in a direction to give the best effect. As a general rule a half section would be made by outlining the figure in full, then cutting out the front quarter by two isometric planes as in Fig. 808, while for a full section

the cut face would be drawn first and the part of the object behind it added afterwards, Fig. 809.

347. Dimetric Projection.—The reference cube can be revolved into any number of positions in which two edges will be equally foreshortened, and the direction of axes and ratio of foreshortening for any one of these positions might be taken as a basis for a system of dimetric drawing. A simple dimetric position is one with the ratios 1 to 1 to $\frac{1}{2}$. In this position the tangents of the angles are $\frac{1}{8}$ and $\frac{7}{8}$, making the angles approximately 7° and 41°. Figure 810 shows a drawing in this system and Fig. 1037 a convenient special triangle for dimetric drawing.

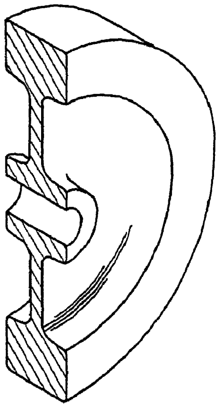


FIG. 809.—Isometric full section.

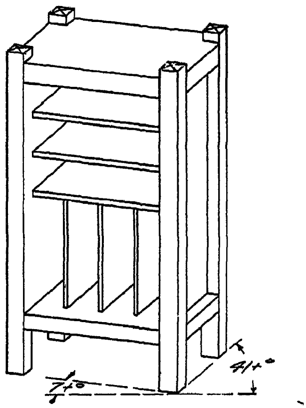


FIG. 810.—Dimetric projection.

348. Trimetric Projection.—Any position with three unequal axes would be called "trimetric." Although with some of these positions the effect of distortion might be lessened, the added time required makes trimetric drawing impractical.

349. Oblique Projecticn.—When the projectors make an angle other than 90° with the picture plane the resulting projection is called "oblique projection." Refer to paragraph 98 with tabular classification. The name *cavalier projection* is given to that special and most-used case of oblique projection in which the projectors make with the plane of projection an angle of 45°. It is often called by the general name *oblique projection* or *oblique drawing*. The principle of it is as follows: Imagine a vertical plane with a rectangular block behind it, having its long edges parallel to the plane. Assume a system of parallel projecting lines in any direction making an angle of 45° with the picture plane (they could be parallel to any one of the elements of a 45° cone with its base in the picture plane). Then that face of the block that is parallel to the plane is projected in its true size, and the edges perpendicular to the plane are projected in their true length. Figure 811 illustrates this principle. The first panel shows the regular orthographic projection of a rectangular block with its front face in the

frontal plane. An oblique projector from the back corner B is the hypotenuse of a 45° right triangle of which AB is one side and the projection of AB on the plane is the other side. When this triangle is horizontal the projection on the plane will be AC. If the triangle is revolved about AB through any angle, β, C will revolve to C' and A_FC_F will be the oblique projection of AB. Since $A_FC_F = A_TC_T$, $A_FC_F = AB$.

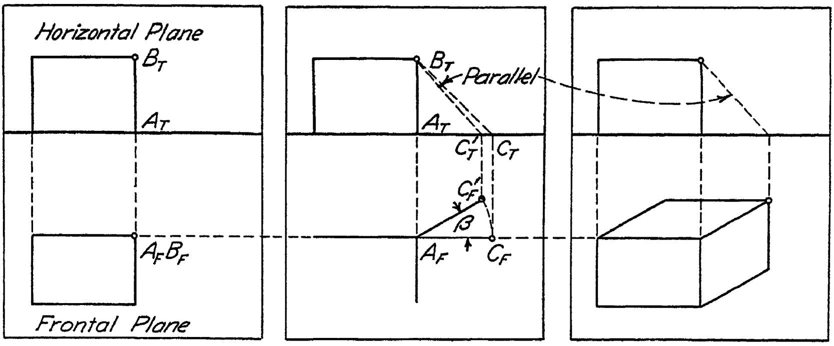


Fig. 811.—Oblique projection and the picture plane.

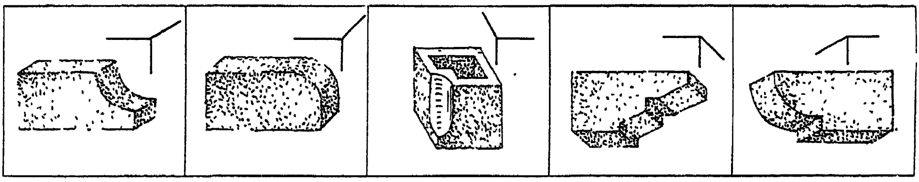


Fig. 812.—Various positions of oblique axes.

350. To Make an Oblique Drawing.—Oblique drawing is similar to isometric drawing in having three axes representing three mutually perpendicular edges, upon which measurements can be made. Two of the axes are always at right angles to each other, being in a plane parallel to the picture plane. The third or cross axis may be at any angle to the horizontal, 30° or 45° being generally used. It is thus more flexible than isometric drawing, Fig. 812. For a rectangular object, Fig. 813, start with a point representing a front corner and draw from it the three oblique axes, one vertical, one horizontal and one at an angle. On these three axes measure the height, width and depth of the object.

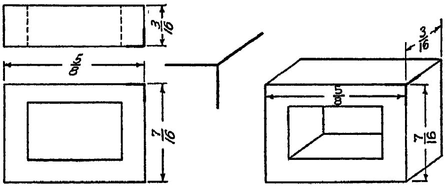


Fig. 813.—Oblique drawing.

Any face parallel to the picture plane will evidently be projected without distortion, an advantage over isometric of particular value in the representation of objects with circular or irregular outline. The **first rule** for oblique projection is, *place the object with the irregular outline or contour parallel to the picture plane.* Note in Fig. 814 the distortion of *B* and *C* over that of *A*.

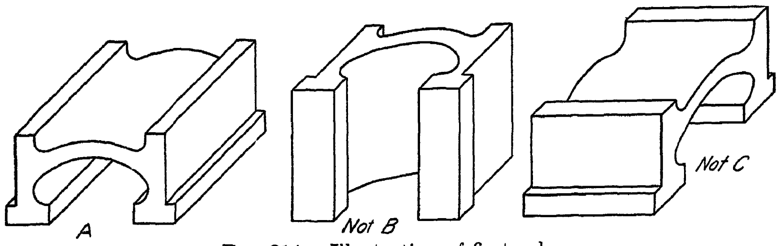


FIG. 814.—Illustration of first rule.

One of the greatest disadvantages in the use of either isometric or oblique drawing is the effect of distortion produced by the lack of convergence in the receding lines—the violation of perspective. This in some cases, particularly with large objects, becomes so painful as practically to preclude the use of these methods. It is perhaps even more noticeable in

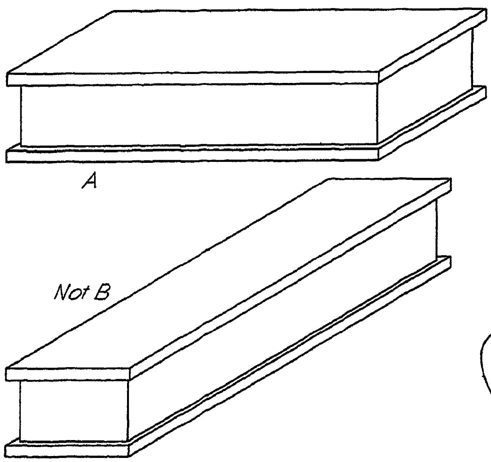


FIG. 815.—Illustration of second rule.

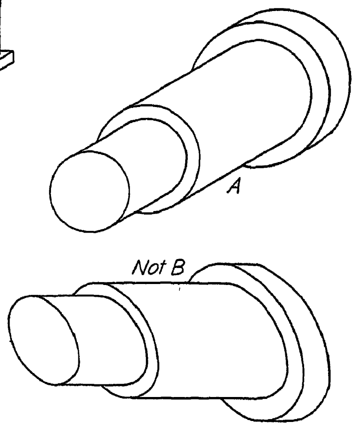


FIG. 816.—Precedence of first rule.

oblique than in isometric and, of course, increases with the length of the cross axis. Hence the **second rule**: *preferably, the longest dimension should be parallel to the picture plane.* In Fig. 815, *A* is preferable to *B*.

In case of conflict between these two rules the first should always have precedence, as the advantage of having the irregular face without distortion is greater than that gained by the second rule, as illustrated in Fig. 816. The first rule should be given precedence even with shapes that are not

irregular if in the draftsman's judgment the distortion can be lessened, as in the example of Fig. 817, where B is perhaps preferable to A.

351. Starting Plane.—It will be noted that so long as the front of the object is in one plane parallel to the plane of projection, the front face of the oblique projection is exactly the same as the orthographic. When the front is made up of more than one plane, particular care must by exercised in preserving the relationship by selecting one of these planes as the starting plane and working from it. In such a piece as the link, Fig. 818, the front bosses may be imagined as cut off on the plane A-A, and the front view, that is, the section on A-A, drawn as the front of the oblique projection. On cross axes through the centers C and D the distances CE behind and CF in front of the plane A-A may be laid off. When an object has no face

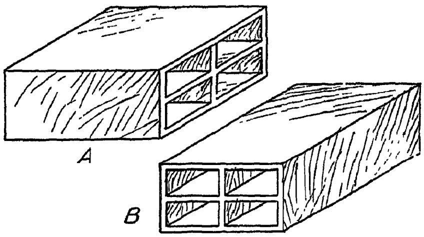


FIG. 817.

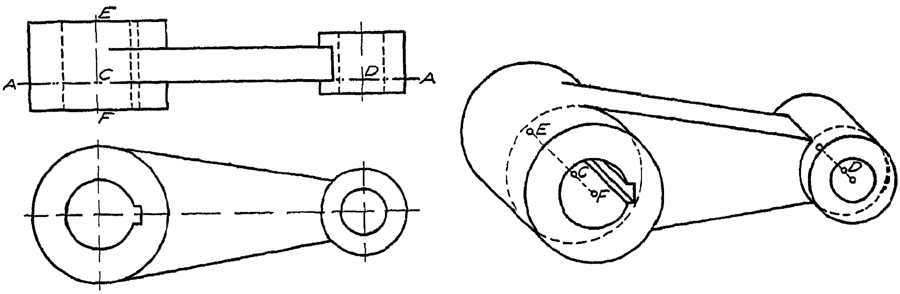


FIG. 818.—Offsets from reference plane.

perpendicular to its base it may be drawn in a similar way by cutting a right section and measuring offsets from it as in Fig. 819. This offset method, previously illustrated in the isometric drawings of Figs. 797 and 798, will

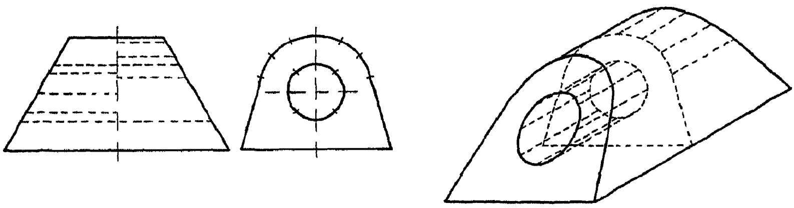


FIG. 819.—Offsets from right section.

be found to be a most rapid and convenient way for drawing almost any figure, and it should be studied carefully.

When it is necessary to draw circles that lie on oblique faces, they may be either plotted and drawn with the French curve or approximated, with circle arcs drawn with the compasses on the same principle as the four-

centered isometric approximation shown in Fig. 802. In isometric it happens that two of the four intersections of the perpendiculars from the middle points of the containing square fall at the corner of the square, and advantage is taken of the fact. In oblique the position of the corresponding points depends on the angle of the cross axis. Figure 820 shows three squares in oblique positions at different angles and the construction of their inscribed circles.

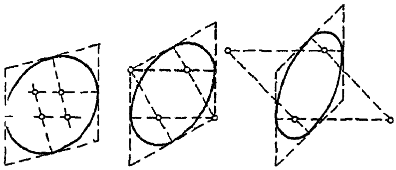


FIG. 820.—Oblique circle construction.

352. Cabinet drawing is that case of oblique projection in which the parallel projectors make with the picture plane an angle of such a value that distances measured parallel to the cross axis are reduced one-half that of cavalier projection. The appearance of excessive thickness that is so disagreeable in cavalier projection is entirely overcome in cabinet projection. The cross axis may be at any angle with the horizontal but is usually taken either at 30° or 45°. The comparative appearances of isometric, cavalier and cabinet drawing are illustrated in Fig. 821.

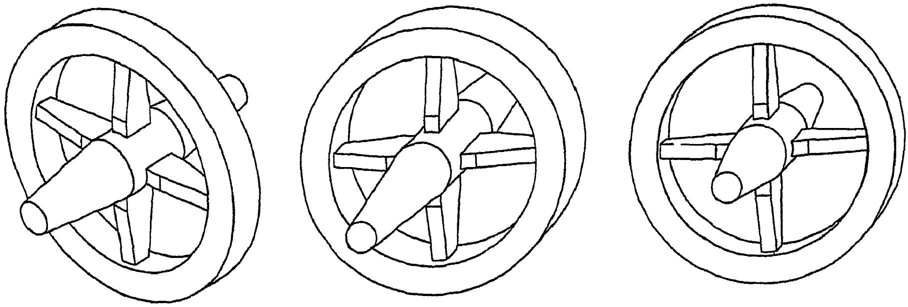


FIG. 821.—Isometric, oblique and cabinet drawing compared.

353. Other Forms.—Cabinet drawing, explained above, is popular because of the easy ratio, but the effect is often too thin. Other oblique drawing ratios such as 2 to 3 or 3 to 4 may be used with pleasing effect.

Pictorial drawings are sometimes made without reference to the theory of projection, on axis combinations of 15° and 30°, 15° and 45°, 15° and 15°, 20° and 20°.

354. Sketching.—One of the valuable uses of pictorial methods is in making freehand sketches, either to illustrate some object or detail of construction or, dimensioned, to form working drawings. The next chapter discusses pictorial sketching, emphasizing the importance of such points as: flattening the axes (the beginner's usual mistake is in drawing them too steep, thereby spoiling the appearance of his sketch), keeping parallel lines parallel and vertical lines vertical, always blocking in circumscribing squares before sketching circles, not confusing the drawing with dotted lines, etc.

PROBLEMS

355. The following problems are intended to serve two purposes: first, furnish practice in the various methods of pictorial representation; and, second, furnish practice in reading and translating orthographic projection.

In reading a drawing remember that a line on any view always means an edge or change in direction of the surface of the object, and that one must always look at another view to interpret the meaning of the line. Do not try or expect to read a whole drawing at a glance.

For convenience in selection and assignment the problems are arranged in groups. Figures from previous chapters may be used to give a further variety of problems.

Do not show hidden lines except where necessary to explain construction.

Group I. Isometric Drawings.—Figs. 822 to 844. Probs. 1 to 23.

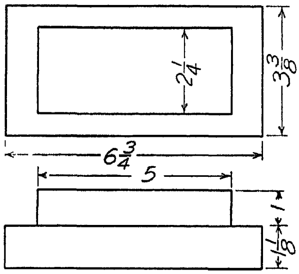


FIG. 822.—Jig block.

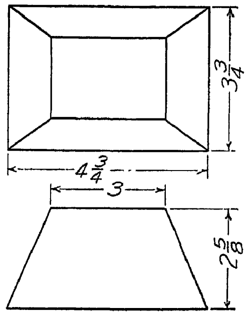


FIG. 823.—Frustum of pyramid.

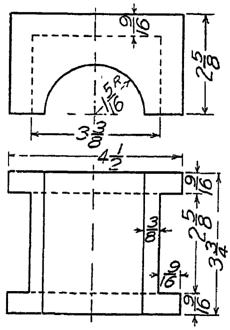


FIG. 824.—Bearing brass.

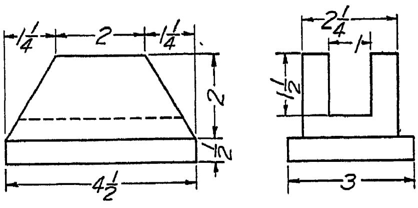


FIG. 825.—Guide block.

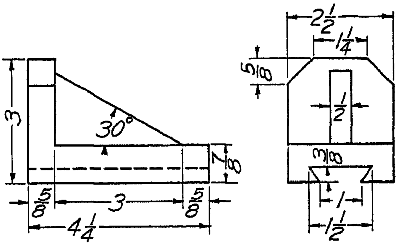


FIG. 826.—Dovetail stop.

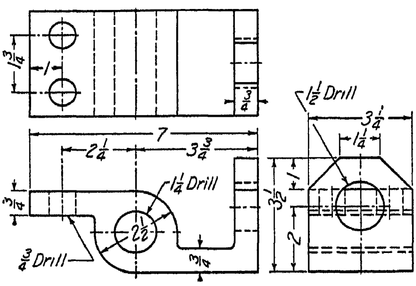


FIG. 827.—Bracket.

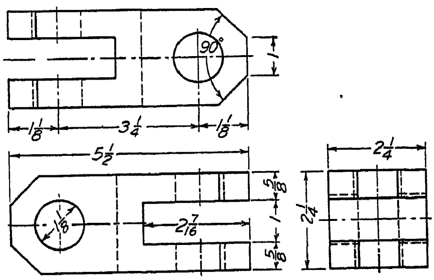


FIG. 828.—Swivel block.

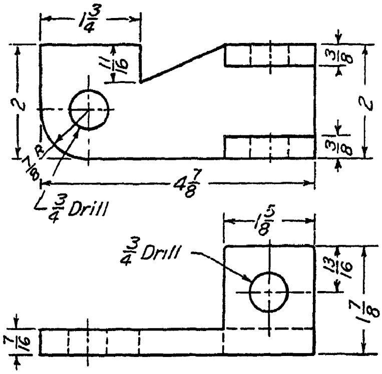


FIG. 829.—Hinged catch.

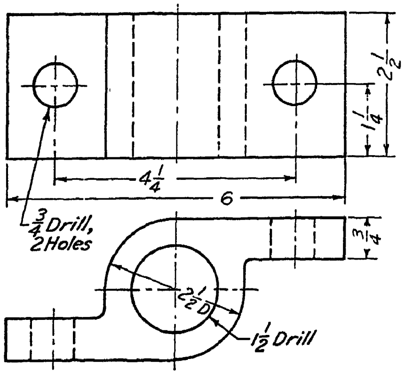


FIG. 830.—Pivot plate.

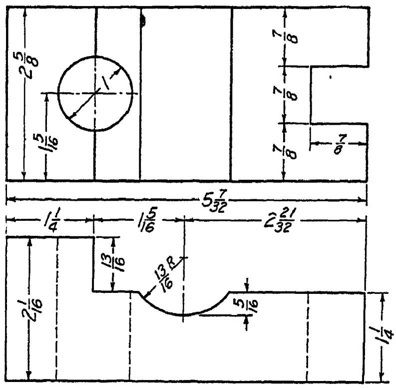


FIG. 831.—Clip half.

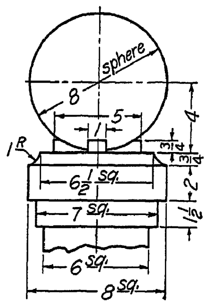


FIG. 832.—Ball finial.

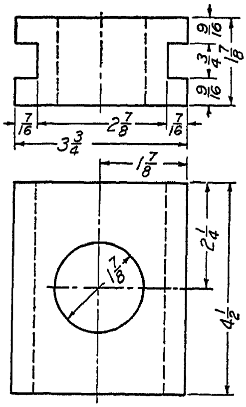


FIG. 833.—Sliding shoe.

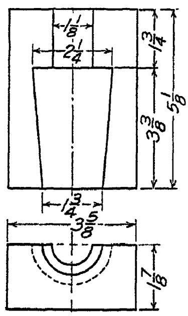


FIG. 834.—Core-box.

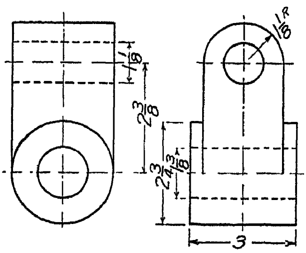


FIG. 835.—Cross link.

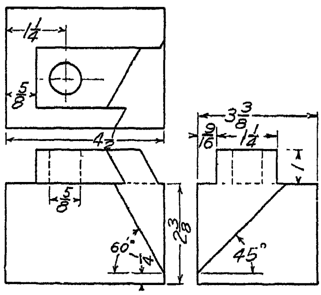


FIG. 836.—Wedge block.

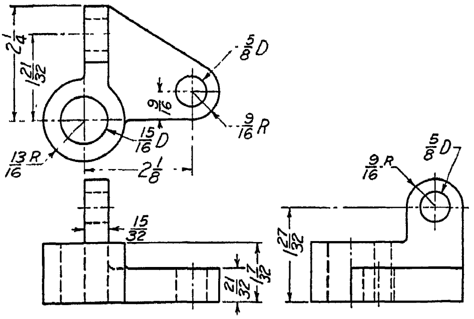


FIG. 837.—Cable clip.

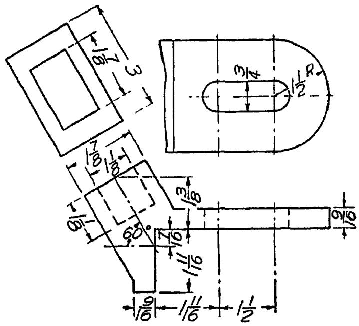


FIG. 838.—Strut anchor.

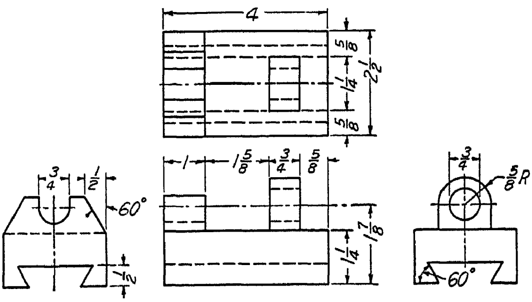


FIG. 839.—Dovetail stop.

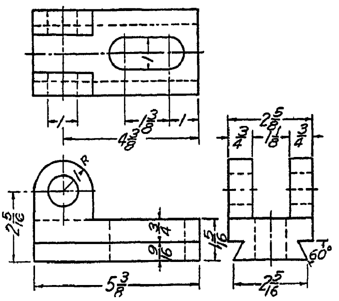


FIG. 840.—Dovetail bracket.

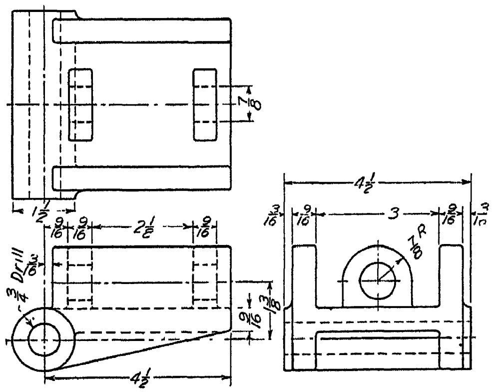


FIG. 841.—Swing plate.

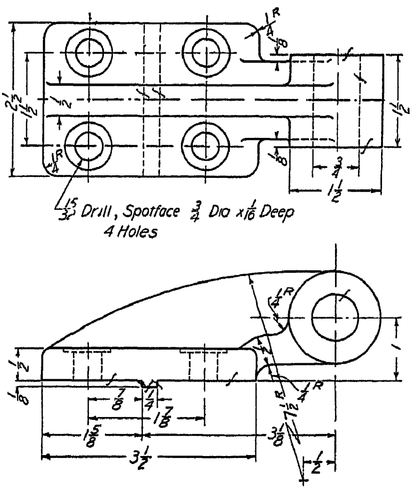


FIG. 842.—Offset side bracket.

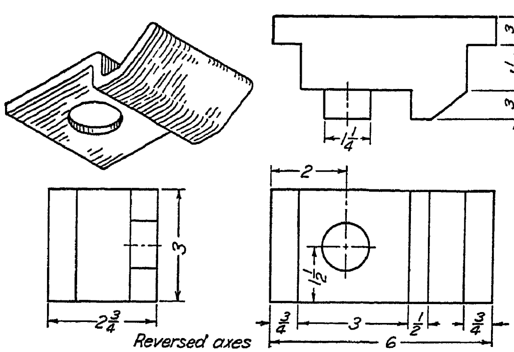


FIG. 843.—Forming punch.

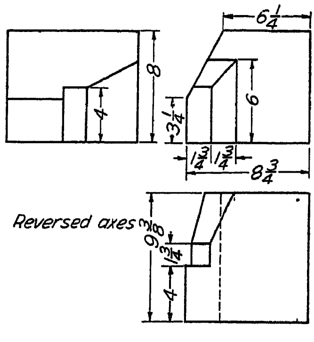


FIG. 844.—Springing stone.

Group II. Isometric Sections.—Figs. 845 to 854. Probs. 24 to 33.

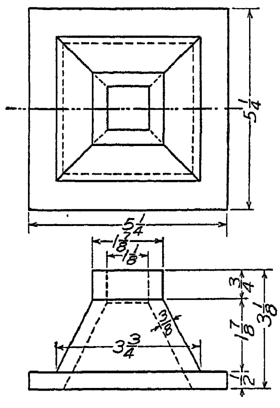


FIG. 845.—Column base.

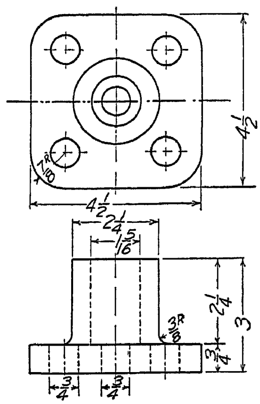


FIG. 846.—Base plate.

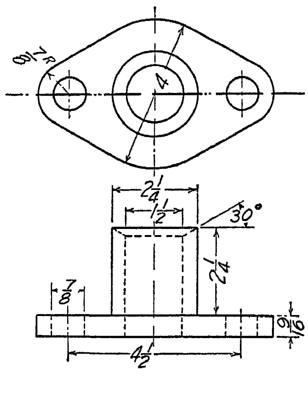


FIG. 847.—Gland.

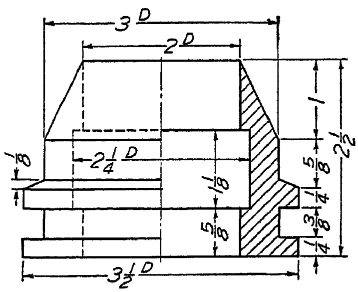


FIG. 848.—Sliding cone.

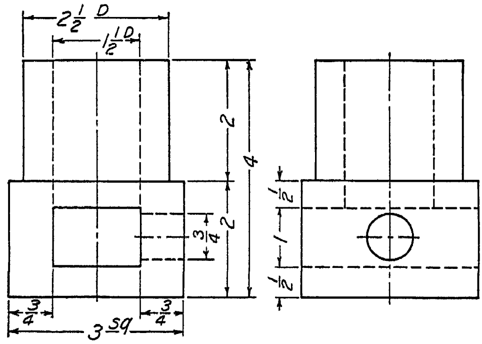


FIG. 849.—Squared collar.

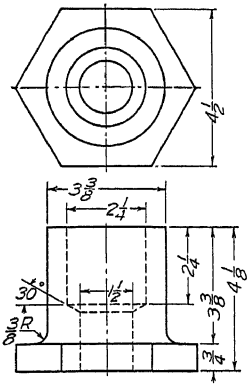


FIG. 850.—Blank for gland.

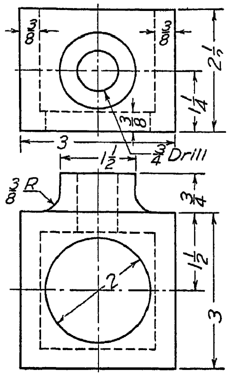


FIG 851.—Sliding cover.

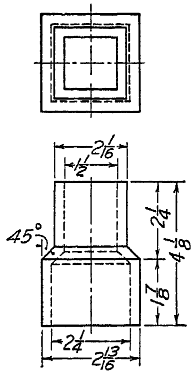


FIG. 852.—Socket for wrench.

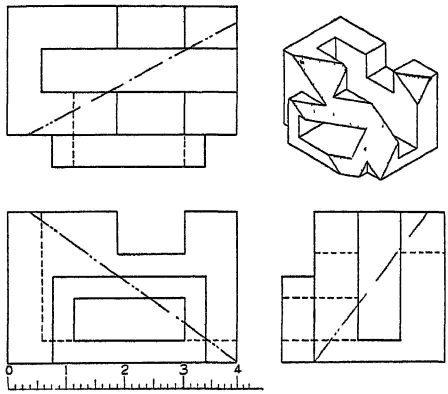


FIG. 853.—Section study.

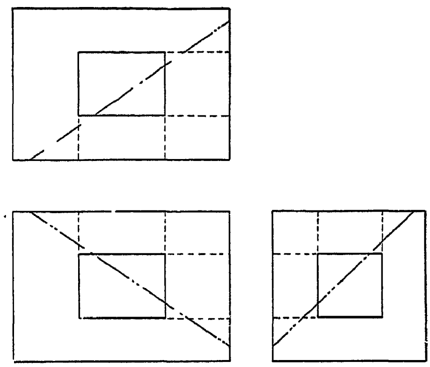


FIG. 854.—Section study.

Group III. Oblique Drawing.—Figs. 855 to 873. Probs. 34 to 52.

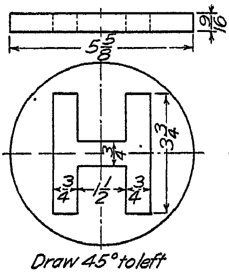


FIG. 855.—Letter die.

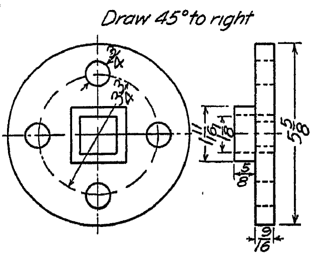


FIG. 856.—Guide plate.

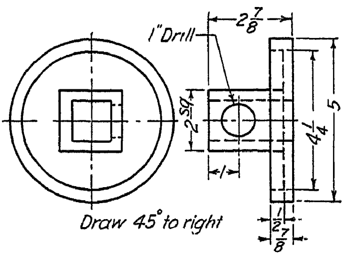
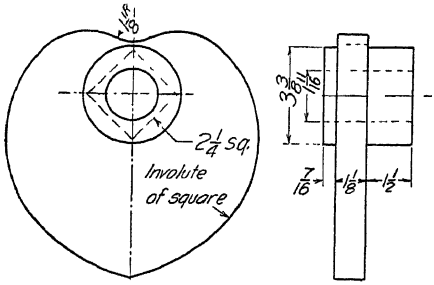
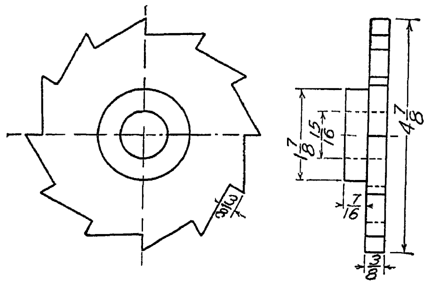


FIG. 857.—Brace base.



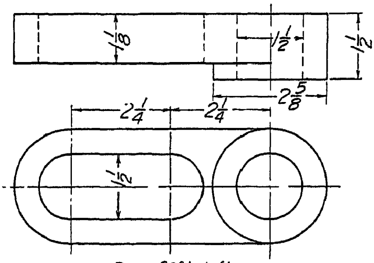
Draw half size and 30° to right

FIG. 858.—Heart cam.



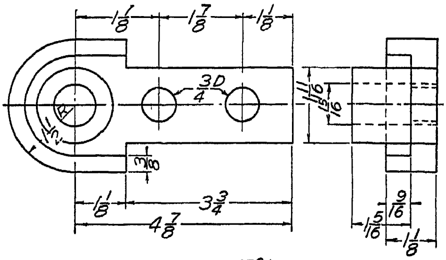
Draw 45° to left

FIG. 859.—Ratchet wheel.



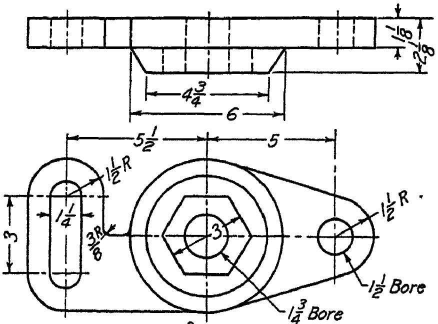
Draw 30° to left

FIG. 860.—Slotted link.



Draw 45° to right

FIG. 861.—Swivel plate.



Draw 45° to left

FIG. 862.—Link.

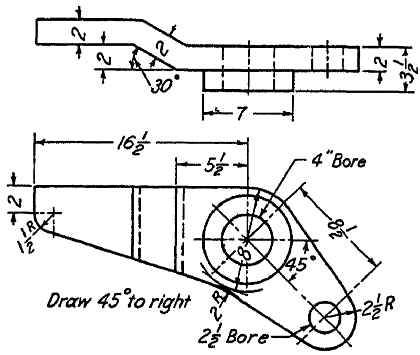


FIG. 863.—Pawl.

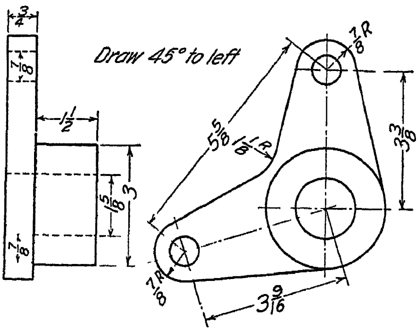
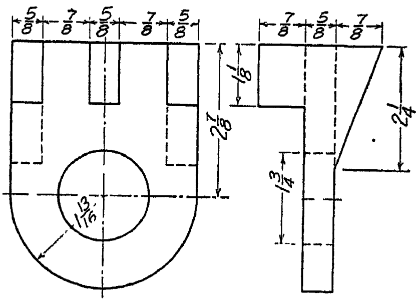


FIG. 864.—Bell crank.



Draw 30° to right

FIG. 865.—Stop plate.

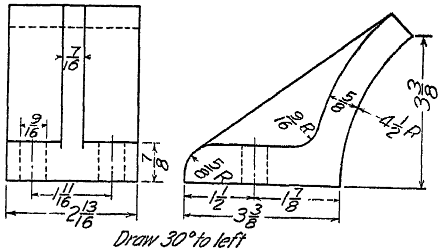


FIG. 866.—Guard bracket.

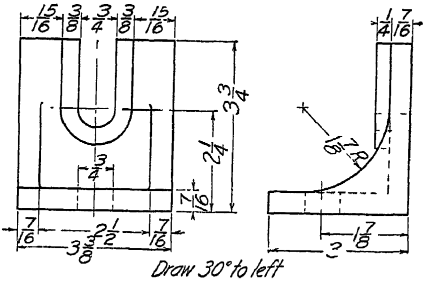


FIG. 867.—Angle yoke.

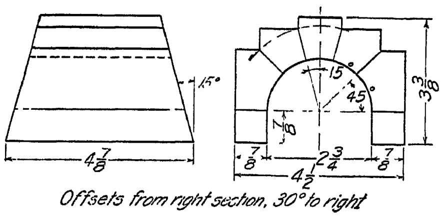


FIG. 868.—Culvert model.

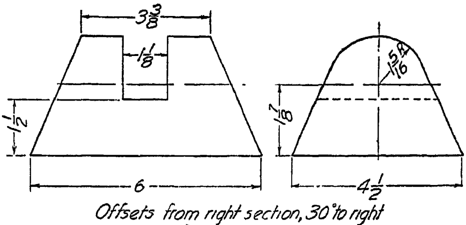


FIG. 869.—Slotted guide.

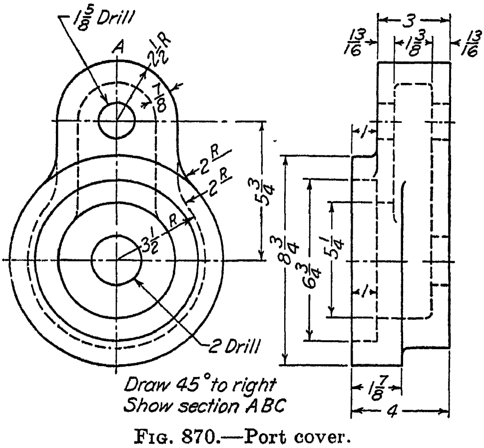


FIG. 870.—Port cover.

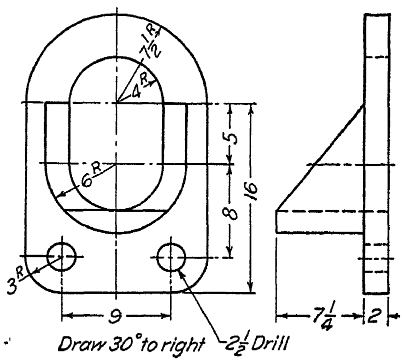


FIG. 871.—Support bracket.

Group IV. Oblique Sections and Half Sections.

53. Fig. 395. Oblique full section of pulley.
54. Fig. 396. Oblique half section of step pulley.
55. Fig. 397. Oblique full section of handwheel.
56. Fig. 398. Oblique full section of flanged wheel.
57. Fig. 399. Oblique full section of flanged pulley.
58. Fig. 400. Oblique half section of V-belt pulley.
59. Fig. 401. Oblique half section of flange.
60. Fig. 874. Oblique full section of wire-rope wedge socket.

Group V. Cabinet and Dimetric Drawing.

Figs. 822, 823, 825, 826, 845, Probs. 61 to 65.

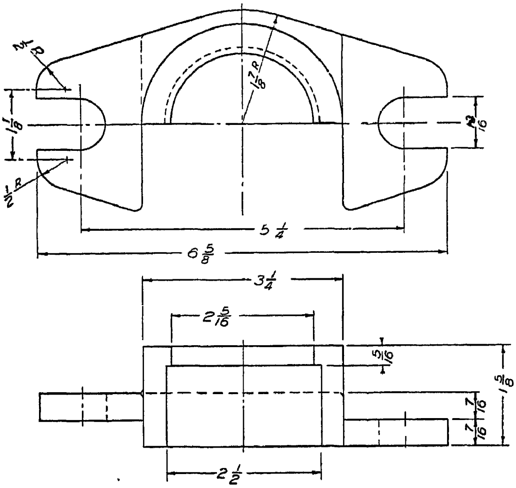


FIG. 872.—Split gland.

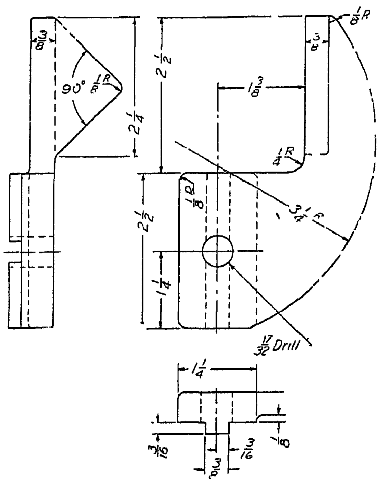


FIG. 873.—Table dog.

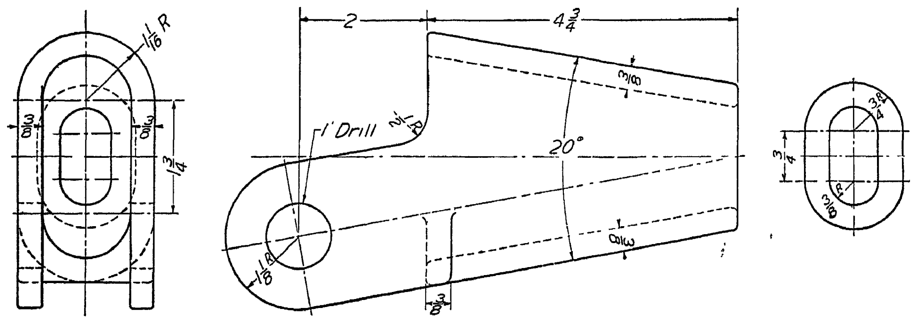


FIG. 874.—Wire rope wedge socket.

Group VI. Pictorial Drawings from Machine Parts.

Machine parts, either rough castings and forgings or finished parts, offer valuable practice in making pictorial drawings. Choose pieces to give practice in isometric and oblique drawings, sections and half sections.

Group VII. Pictorial Working Drawings.

Any of the problems in this chapter offer practice in making complete pictorial working drawings. Follow the principles of dimensioning given in Chap. XI. The form and placement of the dimension figures are given on page 199.

The following problems are suggested:

66. Fig. 825. Pictorial working drawing of guide block.
67. Fig. 829. Pictorial working drawing of hinged catch.
68. Fig. 831. Pictorial working drawing of clip half.
69. Fig. 846. Pictorial working drawing, in half section, of base plate.
70. Fig. 864. Pictorial working drawing of bell crank.

Group VIII. Reading Exercises.—Figs. 875, 876, 877. These figures are to be sketched freehand in one of the pictorial systems, as a test in the ability to read orthographic projections. They may also be used as reading problems by requiring other orthographic views, particularly the figures with two views given. Note that *C*-4 has warped surfaces on the sides.

Find three solutions of figure *Y* and two solutions each for *Z*-1, *Z*-2, *Z*-3 and *Z*-4.

In the last row of Figs. 877, *A*-*A* to *E*-*E*, each problem has several solutions.

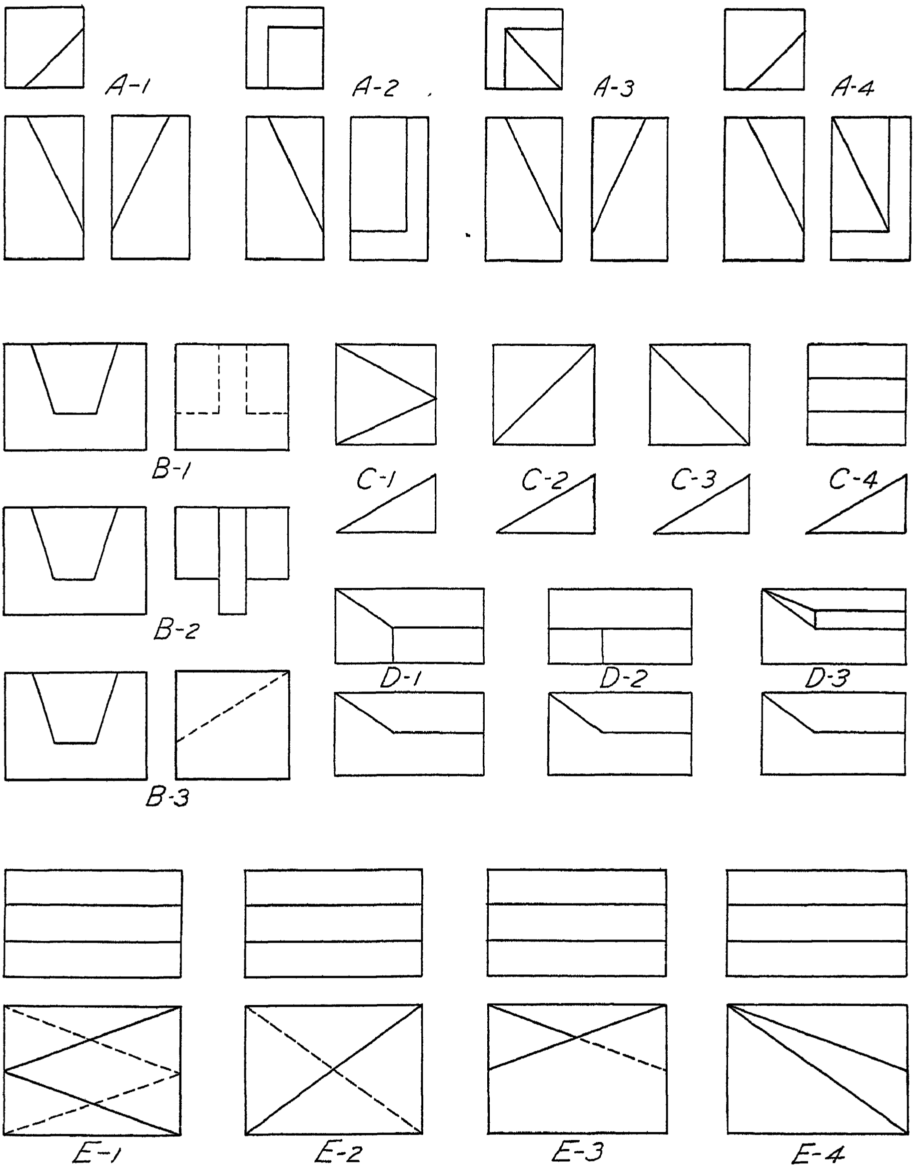


FIG. 875.—Reading exercises.

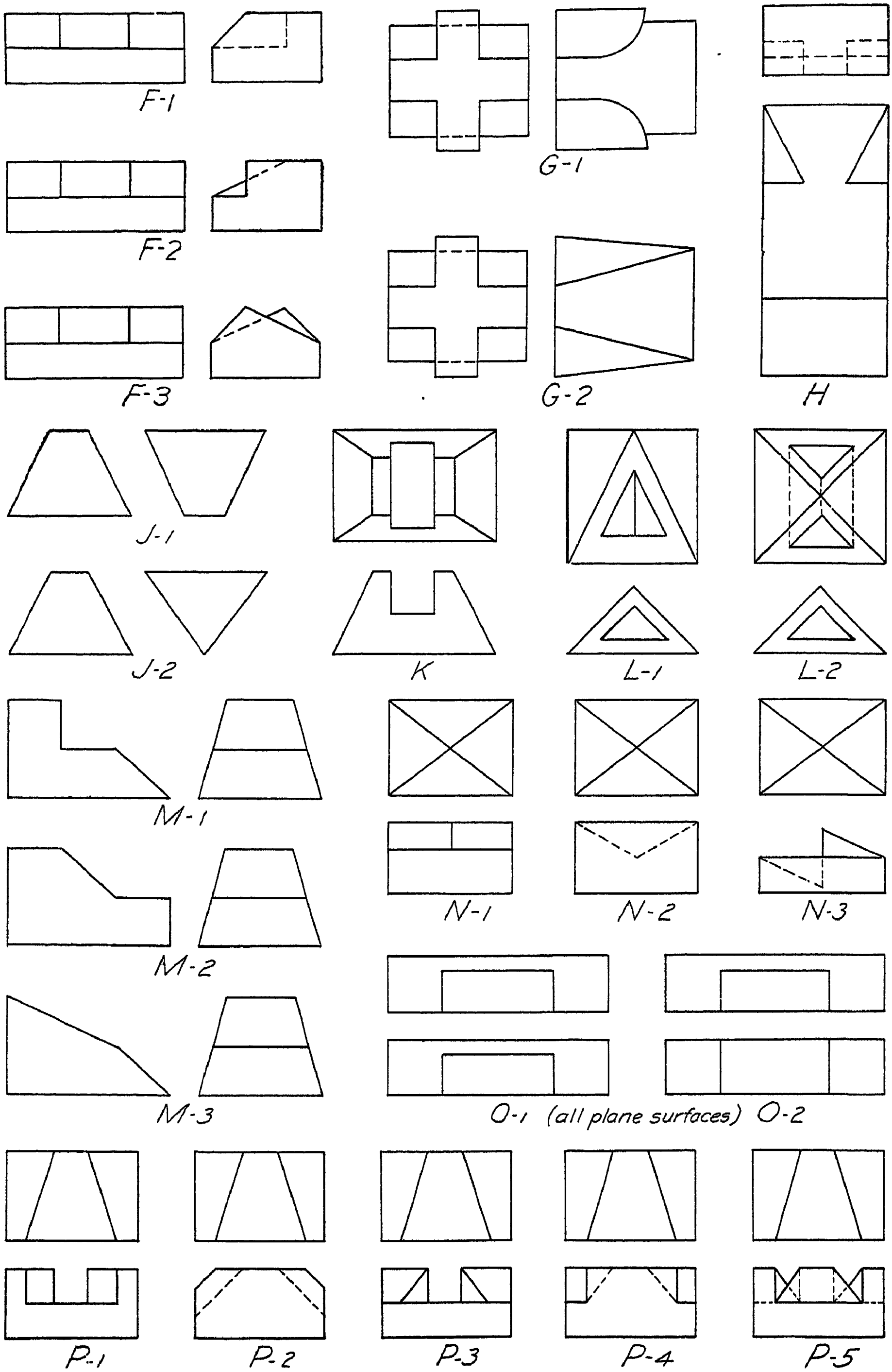


FIG. 876.—Reading exercises.

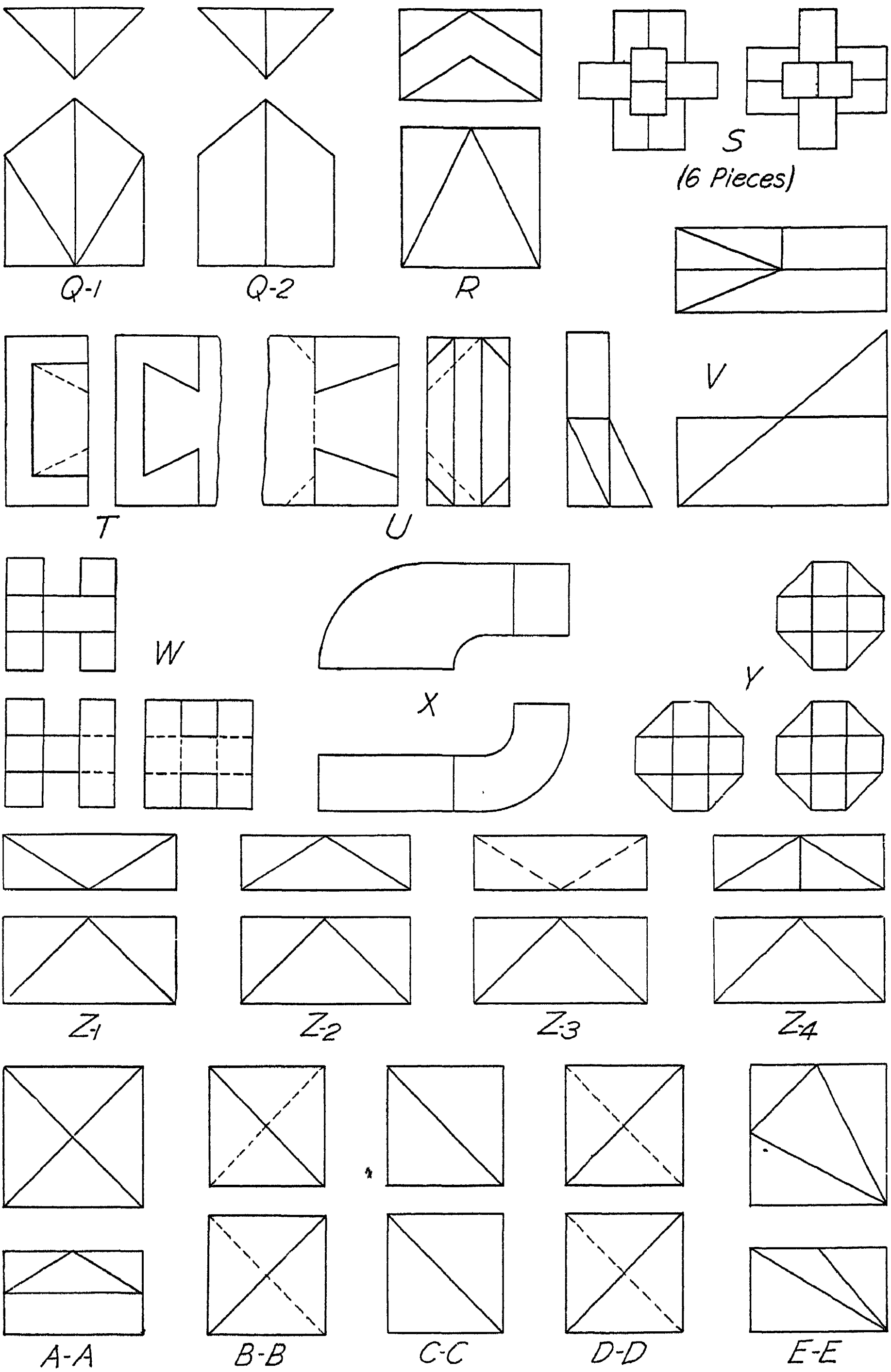


Fig. 877.—Reading exercises.

CHAPTER XXI

PICTORIAL SKETCHING

356. The necessity that the engineer be trained in freehand sketching was emphasized in Chap. XVIII. What was said there, however, referred particularly to sketching in orthographic projection; now let it be remarked that before the engineer can be said to be adequately equipped to use the graphic language, he must possess the ability to sketch *pictorially* with skill and facility.

In designing and inventing, the first ideas come into the mind in pictorial form, and preliminary sketches made in this form preserve the ideas as visualized. From this record the preliminary orthographic design sketches are made. A pictorial sketch of an object or of some detail of construction can often be used to explain it when the orthographic projection cannot be read intelligently by a client or a workman. If a working drawing is difficult to understand, one of the best ways of reading it is to start a pictorial sketch of it. Usually before the sketch is finished the orthographic drawing is perfectly clear. Often again, a pictorial sketch may be made more quickly and may serve as a better record than would orthographic views of the same piece. The young engineer should not be deterred by any fancied lack of "artistic ability." An engineer's sketch is a record of information, not a work of art. The one requirement for both is *good proportion.*

357. Methods.—Although not an accurate classification, there may be said to be three pictorial methods: axonometric, oblique and perspective. The mechanical construction of the first two has been explained in detail in the previous chapter, and the third is explained in Chap. XXII.

358. Axonometric Sketching.—After a clear visualization the first step in the procedure is to select the best position from which to view the object and thus determine the direction of the axes. It will be remembered that there is an infinite number of positions for the three axes that represent three mutually perpendicular lines, and that the simplest is the isometric position. Sketches may be made on isometric axes, but, unless it is important to show some feature on the top, a much better effect is gained and the distortion greatly lessened by drawing the cross axes at a much smaller angle with the horizontal, Fig. 878. Since measurements are not made on sketches, the axes may be foreshortened until the proportion is satisfactory to the eye; moreover the effect of distortion may be overcome still further by slightly converging the receding lines. Objects of rectangular outline are best adapted to sketching in axonometric projection.

A successful method of establishing the direction of the two horizontal axes, used by George J. Hood, is to sketch first a horizontal ellipse (with a little practice this can be done with a free sweep of the arm), Fig. 879. At some point, as A, draw a tangent. Through A and the center of the ellipse

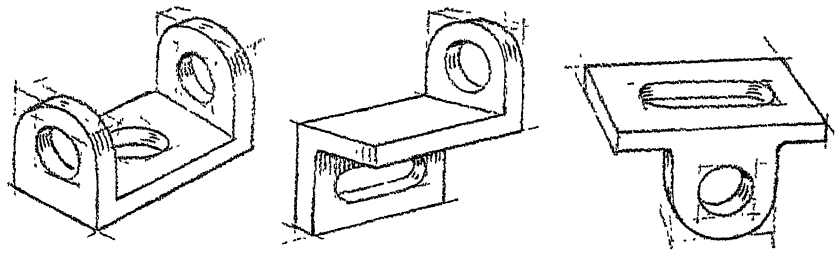


FIG. 878.—Choice of axes.

draw one of a pair of conjugate diameters of the ellipse and at the other end of this diameter a second tangent parallel to the first. Complete the axonometric square by drawing the other two sides parallel to the diameter.

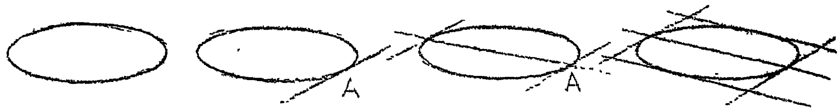


FIG. 879.—Ellipse method of establishing axes.

After setting the axes the sketch should be blocked in by drawing the principal outlines, boxing in the cylindrical parts in their enclosing square prisms. A circle in pictorial drawing is always an ellipse whose major axis is at right angles to the shaft or rotation axis of the circle. Thus its minor

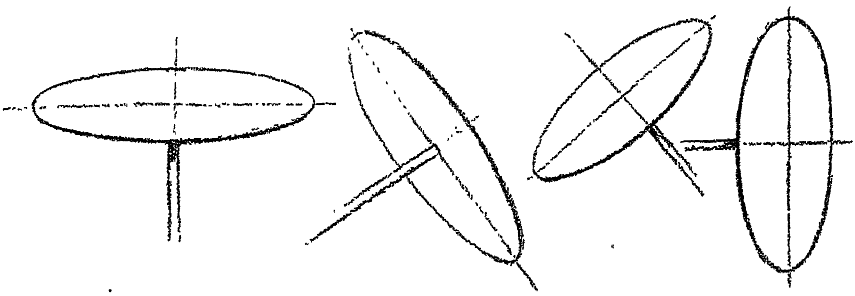


FIG. 880.—Relation of ellipse axes to axis of rotation.

axis coincides on the drawing with the picture of the shaft axis, Fig. 880. Locate these axes and carry the sketch on as suggested in Fig. 881, preserving the proportions by completing the main outlines before adding any minor details. Do not use any hidden lines unless necessary for the description of the piece.

Note particularly that by the above rule *all* circles on horizontal planes are drawn as ellipses *with the major axis horizontal*, Fig. 882.

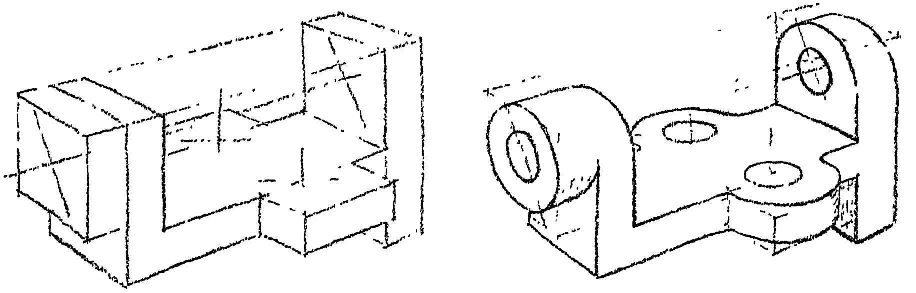


FIG. 881.—Blocking in a sketch.

Some care must be exercised in adding dimensions to a pictorial sketch. The extension lines must be either in or perpendicular to the plane on which the dimension is being given.

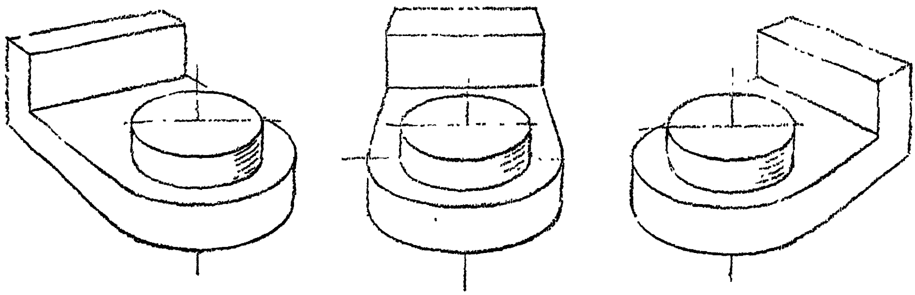


FIG. 882.—Axonometric projections of horizontal circles.

359. Oblique Sketching.—The advantage of oblique projection in preserving one face without distortion is of particular value in sketching, and the painful effect of distortion in oblique drawing done mechanically may be greatly lessened in sketching, by foreshortening the cross axis to a pleasing proportion, Fig. 883. By converging the lines parallel to the cross axis the

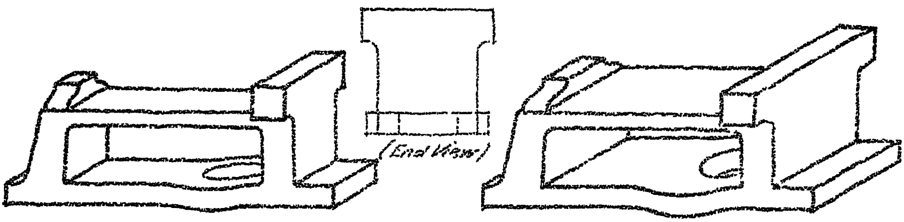


FIG. 883.—Oblique, with and without foreshortening.

effect of parallel perspective is obtained. This converging in either axonometric or oblique is sometimes called "fake perspective."

360. Perspective Sketching.—A sketch made in perspective gives by far the most pleasing pictorial effect. For constructing a perspective drawing of a proposed structure from its plans and elevations a knowledge of the

principles of perspective drawing is required, but for making a perspective sketch from the object one may get along by observing the ordinary phenomena of perspective which affect everything we see: the fact that objects appear smaller in proportion to their distance from the eye, that parallel lines appear to converge as they recede, that horizontal lines and planes appear to "vanish" on the horizon.

In perspective sketching from the model the drawing is made simply by observation, the directions and proportionate lengths of lines being estimated by sighting and measuring on the pencil held at arm's length, one's knowledge of perspective phenomena being used as a check. With the drawing board or sketch pad held in a comfortable drawing position perpendicular to the line of sight from the eye to the object, the direction of a line is tested by holding the pencil at arm's length parallel to the board and rotating the arm until the pencil appears to coincide with the line on the model, then moving it parallel to this position back to the board. The apparent lengths of lines are estimated in the same way; holding the pencil in a plane perpendicular to the line of sight, one marks with the thumb the length of pencil which covers the line of the model, rotates the arm with the thumb held in position until the pencil coincides with another line, and then estimates the proportion of this measurement to the second line, Fig. 884.

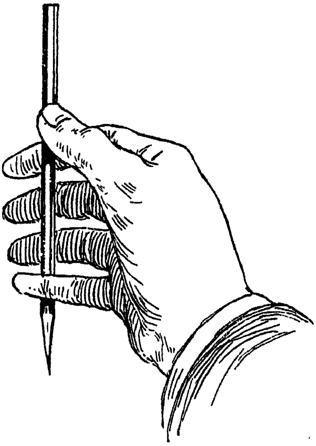


FIG. 884.—Estimating proportion.

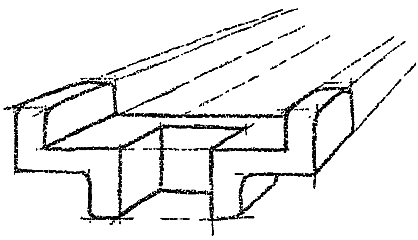


FIG. 885.—Parallel perspective sketch.

The sketch should be made lightly, with free sketchy lines, and no lines should be erased until the whole sketch has been blocked in. *Do not make the mistake of getting the sketch too small.*

In starting a sketch from the object, set it in a position to give the most advantageous view, and sketch the directions of the principal lines, running them past the limits of the figure toward their vanishing points. Block in the enclosing squares for all circles and circle arcs and proceed with the figure, drawing the main outlines first and adding details later; then brighten the sketch with heavier lines. A good draftsman often adds a few touches of surface shading, but the beginner should be cautious in attempting it. Figure 885 shows the general appearance of a "one-point" perspective

sketch before the construction lines have been erased. Figure 886 is a sketch in angular perspective.

361. Sketching from Memory.—After one has become proficient in sketching, the memory for form may be strengthened and the capacity for "stored observation" greatly increased by systematic and regular practice in sketching from memory. The order of this study should be graded carefully: first, easy pictorial drawings to be "read" then "copied" exactly from memory; second, orthographic drawings to be read and copied; third, pictorial drawings to be memorized, then drawn in orthographic; fourth, castings and machines to be studied and drawn from memory in orthographic; fifth, orthographic drawings to be studied, then translated from memory into pictorial sketches.

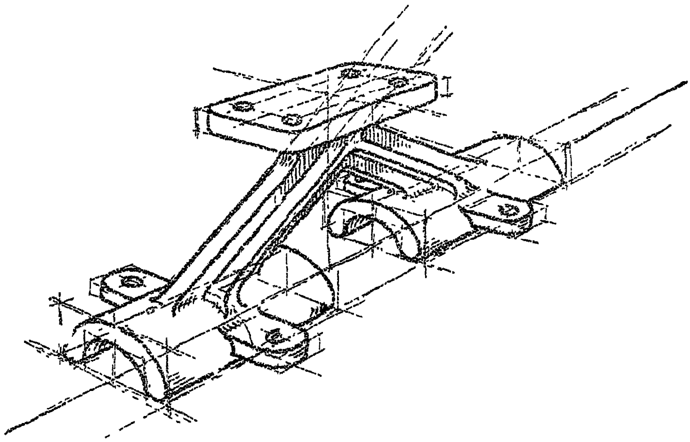


FIG. 886.—Angular perspective sketch.

Study the drawing with close concentration until every detail is stored in the memory for future visualization (the time required for this observation should be noted, although it is not the important factor). Then make an accurate sketch of the object from memory. When finished compare the sketch with the original. The following day make another memory sketch of the same piece without further sight of the original. Carry this practice along, using pieces progressively more difficult. Persevered in for a reasonable time, such practice will give one an ability to remember form and line that will be surprising.

PROBLEMS

Group I. Fig. 887. Make pictorial sketches of the pieces shown in this figure.

Group II. Select from Figs. 822 to 874 some not previously drawn and make freehand sketches in perspective.

Group III. Select one of the objects from Fig. 748, study it with concentration for 20 seconds, close the book and reproduce it.

Group IV. Select one of the pieces from Figs. 875 to 877. Study it for from 10 to 30 seconds, close the book, make a memory sketch of the orthographic projection and then make a pictorial sketch.

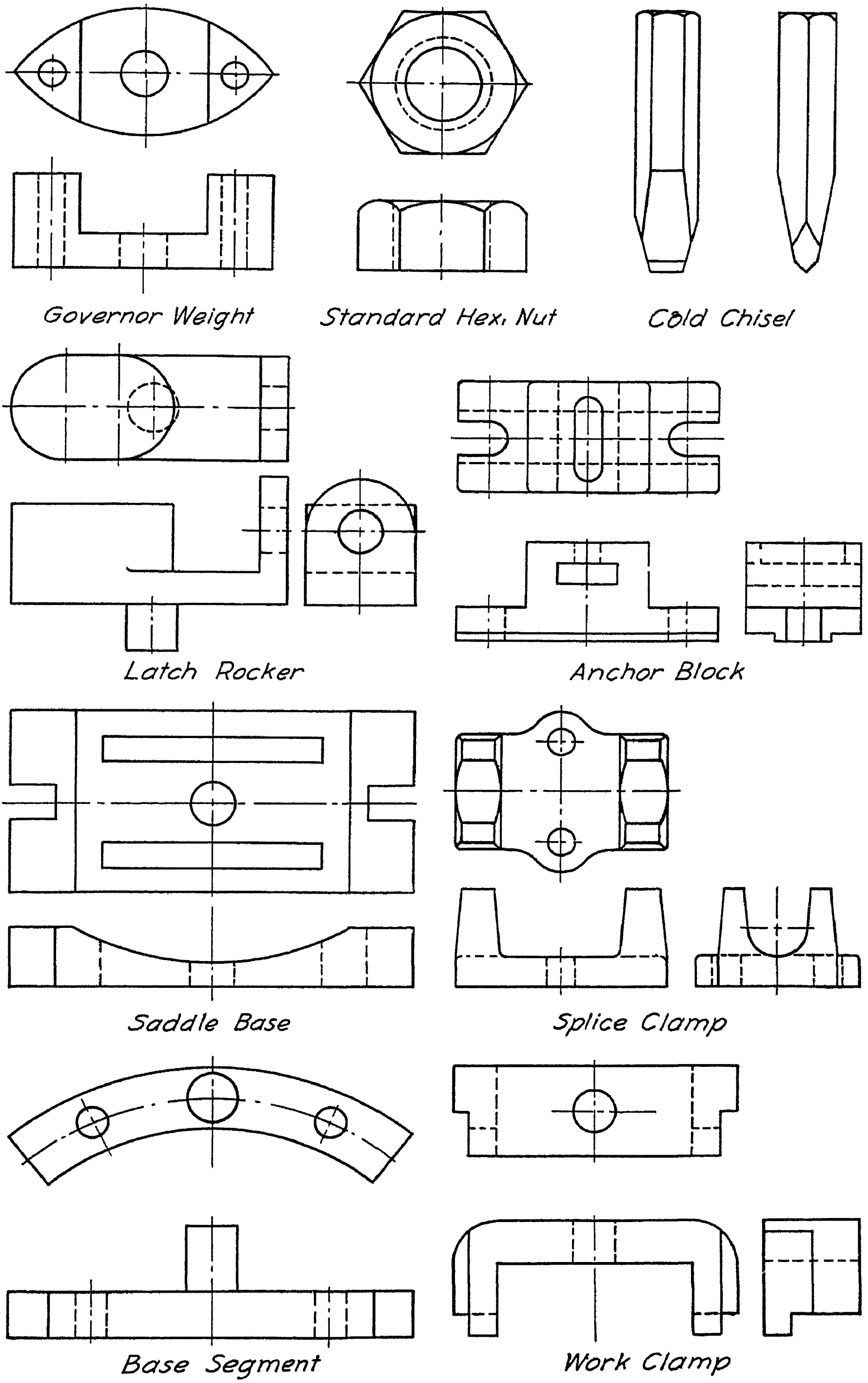


FIG. 887.—Problems for sketching

CHAPTER XXII

PERSPECTIVE DRAWING

362. Perspective drawing is the representation of an object as it actually appears to an observer located at a particular station point. Geometrically it is the figure resulting when the cone of rays from the eye to the object is intersected by a vertical picture plane. There is a distinction between "artists' perspective" and "geometrical perspective" in that the artist draws the object as he sees it projected on the spherical surface of the retina of his eye, while geometrical, or mechanical, perspective is projected on a plane as in a photograph, but except in wide angles of vision the difference is not noticeable.

In a technical way, perspective is used more in connection with architecture than in other branches, but every engineer will find it of advantage to know the principles of the subject.

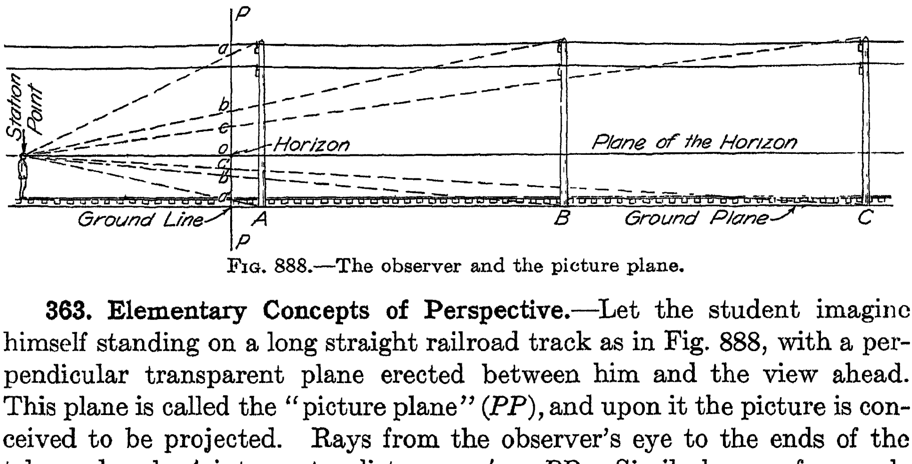


FIG. 888.—The observer and the picture plane.

363. Elementary Concepts of Perspective.—Let the student imagine himself standing on a long straight railroad track as in Fig. 888, with a perpendicular transparent plane erected between him and the view ahead. This plane is called the "picture plane" (*PP*), and upon it the picture is conceived to be projected. Rays from the observer's eye to the ends of the telegraph pole *A* intercept a distance *aa′* on *PP*. Similarly rays from pole *B* intercept *bb′*, a lesser distance. The intercept *cc′* from *C* is still less. These distances *aa′*, *bb′*, *cc′*, etc., correspond in proportion to the heights of the images made upon the retina of the eye by the respective poles *A*, *B* and *C* and agree with our everyday experience—that the farther away an object is, the smaller it appears. It is evident from the figure that, as the succeeding poles in the line are considered, the projection of each upon the picture plane will be shorter than the preceding one. Thus a pole far away on the horizon will show only as a point at *o*. The horizontal plane through this point *o* and the observer's eye is called the "plane of the horizon," and

the horizontal line of intersection of this plane with the picture plane is called simply the *horizon*. Similarly the intersection of the ground plane with the picture plane is called the *ground line*. In drawing large objects the horizon is usually taken at a distance of 5½ feet above the ground plane since that is about the height of a man's eye. The position of the observer is called the *station point*. To avoid a distorted picture it should not be closer to the picture plane than twice the width or height of the object to be drawn.

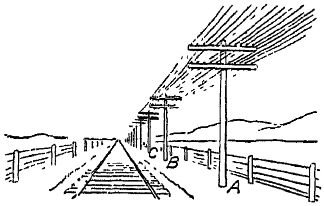


FIG. 889.—The picture

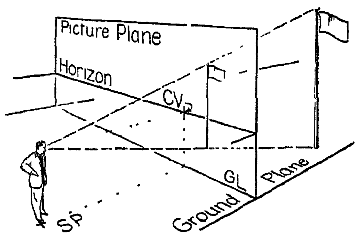


FIG. 890.—Perspective nomenclature.

Figure 889 shows the picture as seen by the observer in Fig. 888. The plane of the paper is the picture plane. The intercepts aa', bb', cc', etc., of Fig. 888 show in the perspective as the heights of the respective poles as they diminish in size and disappear on the horizon. In a similar way the rails converge and vanish. It is evident that all horizontal planes vanish on the horizon line. Therefore *any horizontal line will vanish at some point on the horizon.* A system of parallel horizontal lines vanishes at a single point; thus, as with the telegraph wires and track, *horizontal lines perpendicular to the picture plane vanish at the center of vision,* a point on the horizon directly in front of the observer.

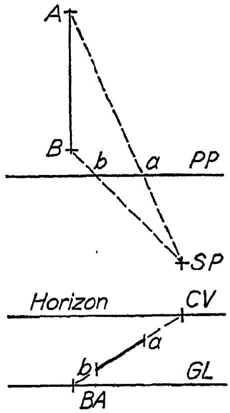


FIG. 891.

Vertical lines, being parallel to the picture plane, pierce it at an infinite distance and therefore do not vanish but show vertical in the picture.

Figure 890 illustrates the perspective terms described.

364. Three Fundamental Lines.—The three commonest directions of lines on a drawing are (1) horizontal profile, perpendicular to the picture plane, (2) vertical and (3) horizontal frontal, parallel to the horizon. A knowledge of their perspective appearance is important. Horizontal-profile lines are called, in perspective, "perpendiculars," because of their relationship to the picture plane.

Figure 891 shows the top and front views of a horizontal-profile line AB, whose perspective is to be drawn. The top view contains also the SP and PP. In the front view are CV, the horizon through CV and the ground line

GL. Draw the top and front views of the rays from *A* and *B* to the eye. The top view shows the ray from *A* piercing the picture plane at *a* and the ray from *B* piercing at *b*. The front views of the piercing points are determined by projecting to the front views of the rays and the perspective *ab* thus found as the front view is the normal view of the picture plane.

In Fig. 892 the perspective of the vertical line *CD* is found by the same method. Since the top views of *C* and *D* coincide, the perspective is always vertical. Figure 893 shows the determination of the perspective of the horizontal-frontal line *EF*. Since the triangle *EFI* is cut by the picture plane parallel to the horizontal line *EF*, the perspective is horizontal. The ties in Fig. 889 are horizontal frontal. Thus, of the three fundamental lines, perpendiculars vanish at the center of vision. Verticals and horizontal frontals do not vanish.

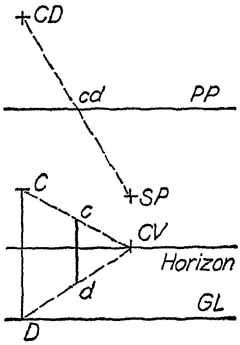


FIG. 892.

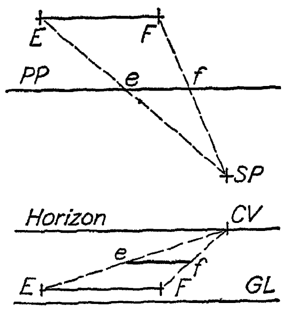


FIG. 893.

365. Vanishing Points.—Any system of parallel lines not parallel to the picture plane will appear to converge at a vanishing point. This point is the intersection of a line of sight (parallel to the system) with the picture plane. Thus all horizontal lines will vanish on the horizon, since all horizontal lines of sight intersect the picture plane on the horizon.

Planes vanish in vanishing lines. Thus all horizontal planes vanish in the horizon.

366. Several methods have been devised to avoid the confusion of lines occurring when the perspective falls over the front view, as it does on the previous figures. One is to omit the front view and give the height dimensions by using another elevation, as a side view.

367. Parallel Perspective.—In Fig. 894 the front view of the object is omitted, and a left side view shows the height. The front *GL* and horizon have been placed in the open space between the *PP* and *SP* of the top view in order to save vertical space.

The wall in the picture plane will be its own perspective. Knowing that the perpendiculars will vanish at *CV*, the verticals appear vertical and the horizontal frontals appear horizontal, and the lower steps and landing can be

drawn by determining one point on the back part of the structure, as A, by means of a ray. Points on the upper steps as B and M can be found by bringing forward construction perpendiculars from the points to the picture plane. Note that measurements can be made only in the picture plane.

Parallel perspective gives a picture similar to oblique projection, as the planes parallel to the picture plane show in their true shape; however, those planes back of the picture plane are of smaller size owing to the vanishing of the perpendiculars. Interiors are often shown by this method.

The perpendicular from B intersects the picture plane at X, which point is its own picture and the *initial point* of the perpendicular. The perspective

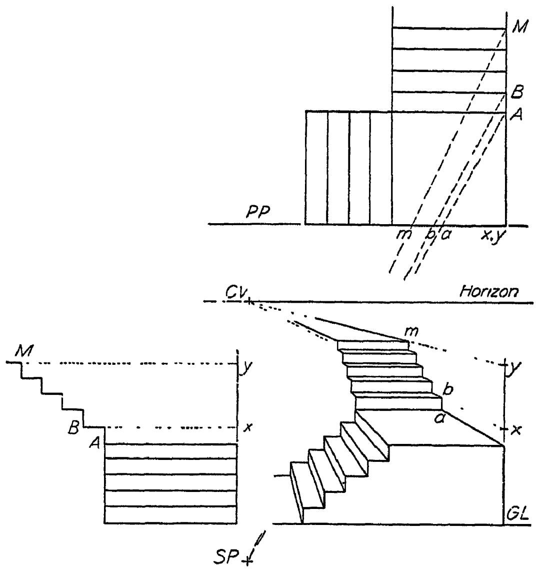


FIG. 894.—Parallel perspective.

of X is therefore directly below the top view of the point and at the height shown in the left side elevation. The picture of the perpendicular is drawn and B located on it by a ray. Other necessary points may be found by similar construction.

The picture is a parallel or one-point perspective, because a principal face of the object is parallel to the picture plane. Only one vanishing point is used, as only one system of parallel lines is at an angle with the picture plane.

368. Angular Perspective.—An angular or two-point perspective is obtained when the object is placed so one of the principal faces is at an angle with the picture plane. In Fig. 895 both the system of horizontal lines on the first face and that in the side face are at an angle with the picture plane, and thus two vanishing points are needed.

Assuming the position of the building and the location of the observer, both in relation to the picture plane, we are ready to construct the perspec-

tive. The vanishing point on the right will be found at the intersection with the picture plane of a horizontal ray making 30° with it, for this ray is parallel to the system of lines which will converge at this vanishing point.

The vanishing point at the left is found by a similar ray. Since A is in the picture plane and on the ground, its perspective is at a, and AB will appear as ab vanishing at the VP on the right; similarly ac is found. Point e will be its true distance above, a, as both are in the picture plane. Now GH is extended, intersecting the picture plane at K, whose perspective k lies the true distance of K above the ground. IJ extended strikes the picture plane at m, again the true height IJ above the ground. n and z are used similarly and the picture completed. It will be seen that all heights are measured in the picture plane either between points on the object which lie in PP, as a

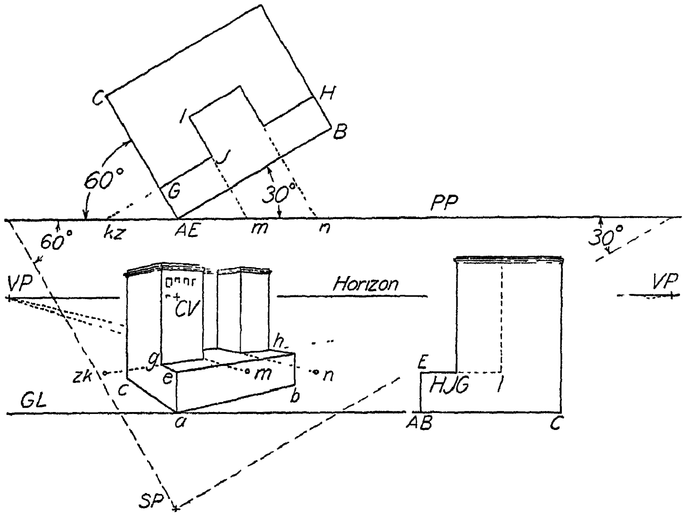


FIG. 895.—Angular perspective.

and e, or to the intersection of construction lines with the picture plane (initial points), as k, m, n and z. It is due to the convergence of parallel lines at a vanishing point that true distances appear only in the picture plane and that measurements must be made in this way.

To make a perspective drawing of an object it is first necessary to have the piece fully described; this is usually done by means of orthographic views. Next the following decisions must be made: (1) the position of the object in relation to the picture plane as on Figs. 894 and 895, (2) the distance of the observer (SP) from the picture plane (this distance should be at least twice the longest dimension of the object) and (3) the height of the observer's eye above the ground, usually 5½ feet, except for birdseye or airplane views, when the distance is much greater, or for small objects which would normally be viewed on a table, when the distance is much smaller. With these facts the perspective can be drawn.

369. Circles in Perspective.—The perspective of a circle is an ellipse unless the plane of the circle is parallel to the picture plane. The axes of the ellipse can be determined only by considerable geometric construction, so the curve is usually found point by point. The perspective of the enclosing square is drawn, and the points on the circle located from the square, as in the circle on the left side of the cube in Fig. 896. Any points on the circle may be used but some order should be followed, as points in the 30°, 45° and 60° lines, for such a method will save time and give greater accuracy.

Another method of construction which can be used to advantage is that of the enclosing octagon. Four sides of the octagon are along the sides of the square while the others are parallel to the diagonals of the square and tangent to the circle. This method gives eight points of tangency through

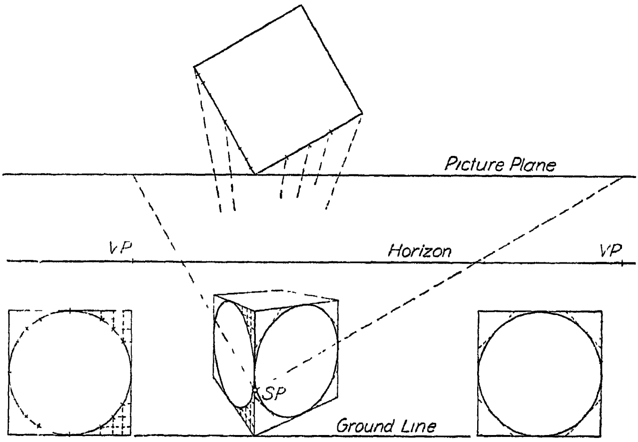


FIG. 896.—Circles in perspective.

which the curve is drawn, as in the circle on the front face of the cube in Fig. 896.

370. The Revolved-plan Method.—The perspective of any point may be obtained by drawing the perspective of two lines through the point, as has been illustrated previously. In drawing a perspective by revolved plan this principle is used. In Fig. 897 the plan, $ABCD$ as shown by dashed lines, has been revolved, using the ground line as an axis, until it occupies the position AB_rC_rD in the ground in front of the picture plane. Since the points are to be determined by the intersection of perpendiculars (lines perpendicular to the picture plane) and diagonals (horizontal lines at 45° to the picture plane), the vanishing points of the two systems of diagonals are found by locating the intersection of the picture plane and a line of sight from the observer parallel to each diagonal system. The perpendiculars, as AB and DC, have their initial points in the GL from A to D and vanish at CV. The diagonals are used to determine the depth dimensions. From E_r a diagonal is drawn intersecting the picture plane at P, which becomes the initial point of the diagonal. Since before the revolution of the plan this line

would have occupied the position *EP*, the perspective runs from the initial point *P* to the *left VP*. The point *F* lies at the intersection of this diagonal and the perpendicular from *D*. Thus *f* is found at the intersection of the perspectives of these lines. Other points are located in the same way. One of the other system of diagonals, *HJ* extended, has its initial point at *H*, vanishes at the right *VP* and locates many points. The whole pattern is built up by the use of the perpendiculars and diagonals and without the use of the cone of rays.

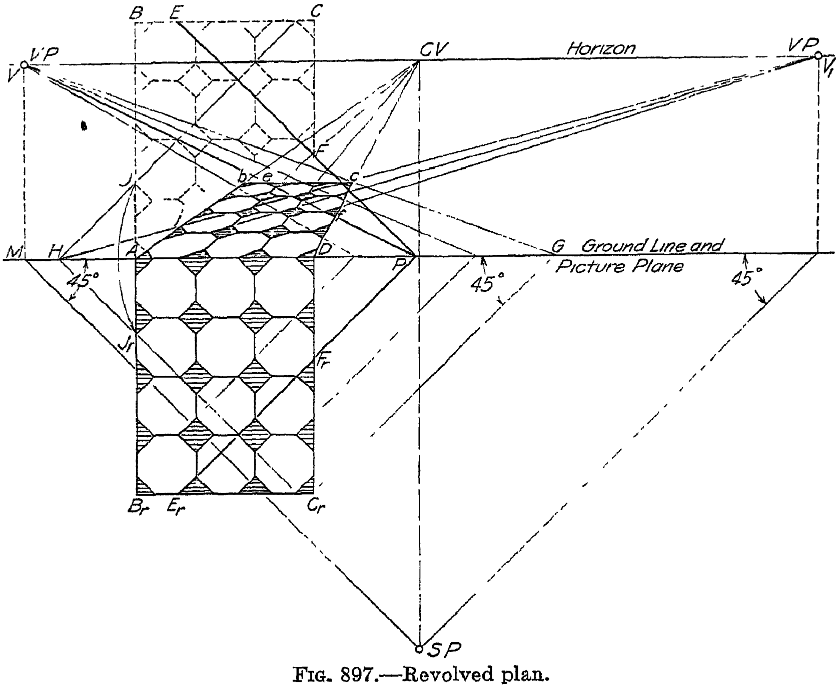


FIG. 897.—Revolved plan.

371. Measuring Points.—A further examination of Fig. 897 will show that the perspective may be found without the plan, either in original position or revolved, if the dimensions are known.

The picture was determined by the use of perpendiculars and diagonals, the former giving width dimensions and the latter depth. Using the same object the initial points of the perpendiculars *A* to *D* can be determined by measurement without use of the plan, and the perpendiculars can be drawn in perspective. If the distance between the point *F* and the picture plane (*FD*) is known, it can be laid off along the *GL* from *D* to *P*, as *FP* is a 45° line. *P* is the initial point of the diagonal through *F* and *E*, which can now be drawn. Also, $GD = DC$ and *G* may be located with its diagonal. Thus the perpendiculars and diagonals can be found and the perspective drawn. A diagonal such as *FP* is actually a measuring line because, owing to its direc-

tion, by laying off DP in the picture plane the same distance can be cut off in DF along a perpendicular.

372. Measuring Points in Angular Perspective.—Measuring lines are determined in space with a direction such that their intercepts in the picture plane are the same as those along a certain line on the object to be drawn. Distances may then be laid out along this certain line by making measurements in the picture plane and using measuring lines. Thus in Fig. 898, with a building at 30° with the picture plane, with $AB_0 = AB$, MN has a direction such that its intercept in the picture plane AB_0 is the same as the intercept along a line at 30° with the picture plane AB. PQ cuts off the same distance along the front of the building as in the picture plane. The vanishing point of the system of MN and PQ, called a "measuring point," is

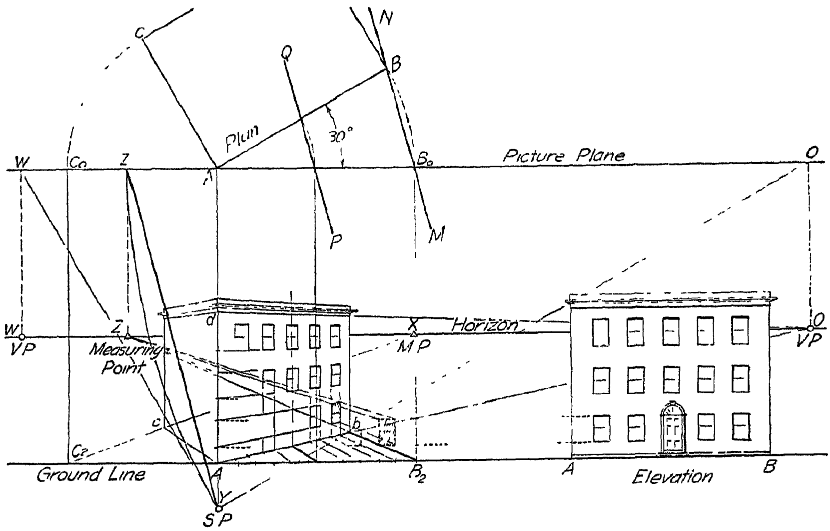


FIG. 898.—Angular perspective, using measuring points.

located at Z by having the observer look parallel to the system. But one of the reasons for using measuring lines is to obviate the use of a plan, so if the plan is necessary to locate the MP, much of the advantage of their use is lost. However, the MP can be located without the plan, for in the two triangles ABB_0 and OYZ, AB is parallel to YO, AB_0 is parallel to OZ and BB_0 is parallel to YZ. Thus the triangles are similar, and, since $AB = AB_0$, $YO = OZ$, or the distance (true length of top view) from SP, Y to vanishing point O is equal to the distance from the vanishing point O to the measuring point Z. Thus the measuring point can be found without the use of the plan. To measure horizontal distances along the end of the building, another system of measuring lines must be used with a different MP, namely, X, and thus $YW = WX$.

With the lines from A to the two vanishing points drawn, b is located by laying the distance AB along GL at AB_2, with measuring line vanishing at

MP, namely, *Z*. *C* is located in the same manner. Heights are measured in the picture plane along *Ad*, while the front windows are located by measurements in the ground from *A* to B_2, measuring lines to the building, and the distances are carried up to the front.

373. In Fig. 899 a building 15′ wide and 8′ deep has its front at 30° with the picture plane toward the right and its near corner 5′ to the right of the axis and 4′ behind the picture plane. After locating *SP* and *CV* and then determining the vanishing points and measuring points, the near corner can be located as follows: the perspective of a perpendicular through the near corner can be drawn by locating its initial point *A* 5′ to the right of the axis and making it vanish at *CV*. A diagonal making 45° with the picture plane can be imagined through the near corner. This diagonal will have its initial point *B* 4′ to the left of *A* and will vanish at its vanishing point *W*. The

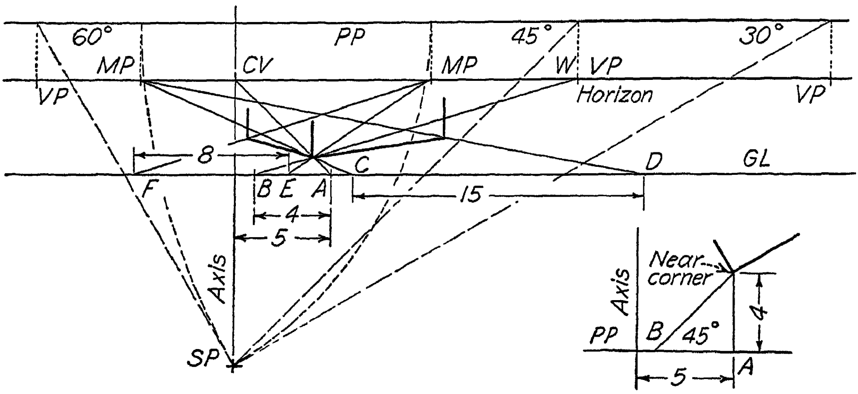


FIG. 899.—Locating a point behind the picture plane.

intersection of the perpendicular and diagonal is the near corner. The small plan shows the perpendicular and diagonal through the near corner. However, this view is not actually drawn but only visualized.

With the near corner located, a measuring line having its initial point at *C* can be drawn from the left *MP* through the near corner. Measuring 15′ from *C* to *D* the initial point of a second measuring line is located. This measuring line cuts off 15′ along the front of the building, as the lines have a direction such that the intercept in the picture plane *CD* is the same as that along the front of the building. From the right *MP* the measuring line is drawn to its initial point *E*, from which 8′ is measured to *F*, and thus the side of the building is determined. Using the measuring points the walls are determined.

Measuring points make it possible to draw the perspective of an object if its description is available. If this description is written, the perspective is made without the necessity of first making the orthographic views. If the description is given by plan and elevation at a scale which would not produce a perspective of the desired size, measuring points make it possible to draw

the perspective at the size wished for without redrawing the plan and elevation.

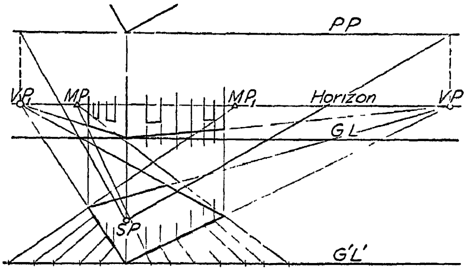


FIG. 900.—The perspective plan method.

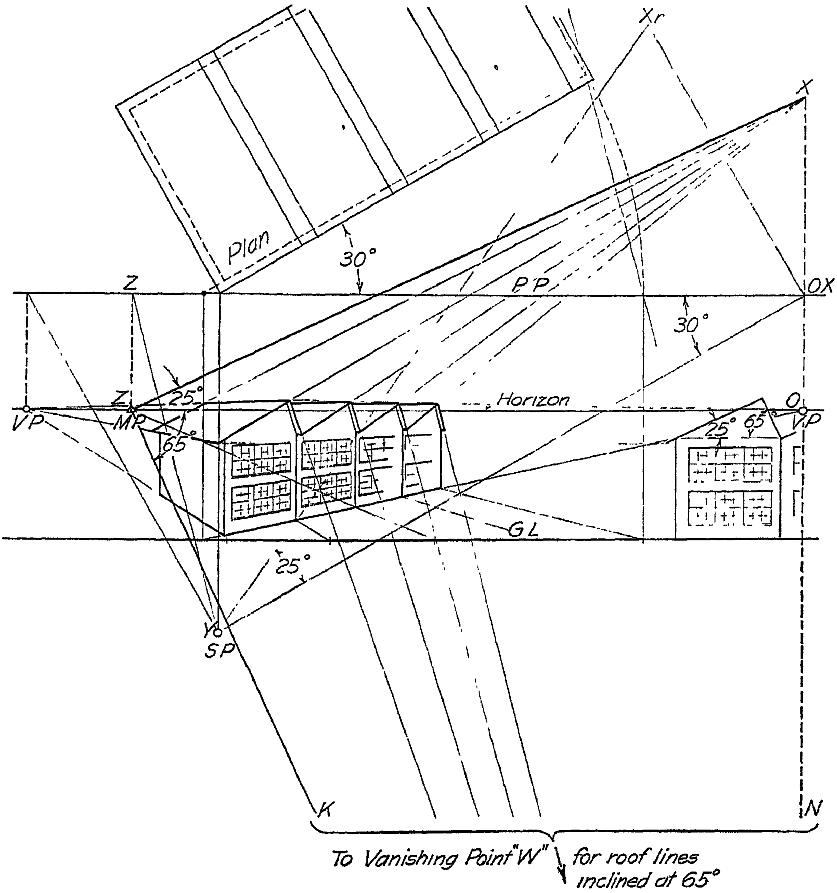


FIG. 901.—Vanishing points of inclined lines.

374. Perspective Plan.—Many times it is well to draw a perspective of the plan from which the vertical measurements can be determined and the perspective built up. In exterior views with the horizon only 5½ feet above

the GL, the plan becomes so flat that it is difficult to make accurate locations. If a secondary ground line is assumed at some distance either above or below the real GL, the plan is opened, giving better working conditions. Fig. 900.

375. Inclined Lines.—Although the perspective of any inclined line can be found by locating the perspectives of any two points on the line it is often advantageous to find the vanishing point of the line. It is particularly necessary if there are several parallel inclined lines and is found by locating the intersection of a line of sight parallel to the system and the picture plane.

In Fig. 901 one system of inclined lines is at 25° with the horizontal. A line of sight parallel to the system will have a top view lying along YO, but as the line is inclined at 25° rather than horizontal, the intersection with the picture plane is not at O but at some point X directly above O. The true distance OX is found by constructing a true view of the right triangle YOX in the revolved position YOX_r. In this construction the axis YO remains unchanged. YX_r is laid off at the angle of inclination from YO and with the right angle at O, the triangle is completed.

The distance OX_r is then laid off above the front view of O, and X is found. X can also be found by drawing ZX at 25° to the horizon, the triangle ZOX being congruent with the triangle YOX_r, as $ZO = YO$, and the angle at Z equals the angle at Y. By this method the vanishing point W of the 65° lines is located. W falls below the horizon because the line of sight parallel to the 65° system runs downward from the eye.

The line XOW is the vanishing line of all vertical planes making 30° with the picture plane to the right.

PROBLEMS

1, 2. Figs. 902, 903. Make perspective drawings to convenient size.

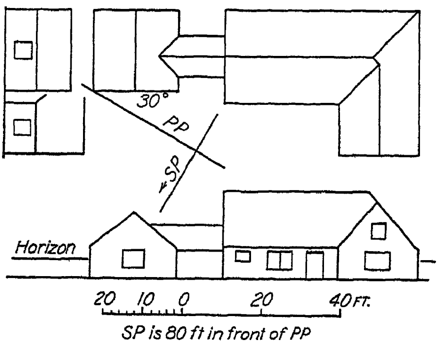


FIG. 902.

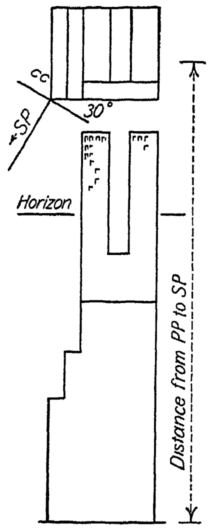


FIG. 903.

CHAPTER XXIII

AIRCRAFT DRAWING

376. In preparation for aircraft drawing the requisites are a thorough knowledge of orthographic projection and descriptive geometry, an acquaintance with shop practice, including riveted construction and welding, experience in the use of sheet-metal stamped shapes and, desirably, a facility in using perspective and other pictorial methods. Aircraft drawing differs somewhat from machine drawing because of the type of structure and the material used. In fuselage and wing and in tail and rudder structure the use of stamped metal with standard small angles, etc., to make up the inner construction and permit the application of a perfect outer surface or "skin" presents problems in drawing otherwise rarely encountered. Perhaps in no other branch of engineering is it so necessary that the engineer be a skilled draftsman. Indeed in some drafting rooms the distinction between designers and draftsmen is not made, as the designers are the draftsmen.

Drawings used in the aircraft industry may be classified under three general divisions: (*a*) preliminary design drawings, (*b*) layout drawings and (*c*) production drawings.

377. Preliminary Design Drawings.—The drawings used in designing may be again classified somewhat in the order in which they are started, although they are carried along concurrently. In the industry these divisions are called (1) *preliminary "three-view" drawing,* (2) *inboard profile,* (3) *wing drawing and details* and (4) *master diagram.*

Three-view Drawing.—The three-view drawing is a preliminary drawing with top, front and side views on one sheet, made for study of the general relationship of fuselage, wings and tail. This drawing is the basis of all design work. On it the designer studies the placement of the wings, the placement and general design of the landing gear, arrangement of equipment and the form and blending of the various surfaces. The views are arranged as in Fig. 904, although this figure is shown to give the names of the principal parts of an airplane.

Inboard Profile.—The inboard profile is a section taken longitudinally through the center of the fuselage together with a sectional top view, showing the structure and the arrangement of equipment to larger scale and in greater detail than does the three-view drawing. Several typical cross sections may also be included on this sheet, showing general structure and clearances. Figure 905 shows a part of an inboard profile, much reduced.

It is universal practice on all aircraft drawings, both assembly and detail, to have the nose to the left, or pointing west.

Wing Drawing and Details.—This drawing shows in detail the structure of the wings and the method of fastening to the fuselage. The wing shape is described by a top view, front view and side view, with a number of detail sections to show construction. Figure 906 is a portion of a wing drawing.

Master Diagram.—The master diagram is an accurate center-line skeleton drawing, which shows the locations but omits the details of all major structural parts of the plane, and includes spans, lengths, height, wheel tread, clearances, etc.

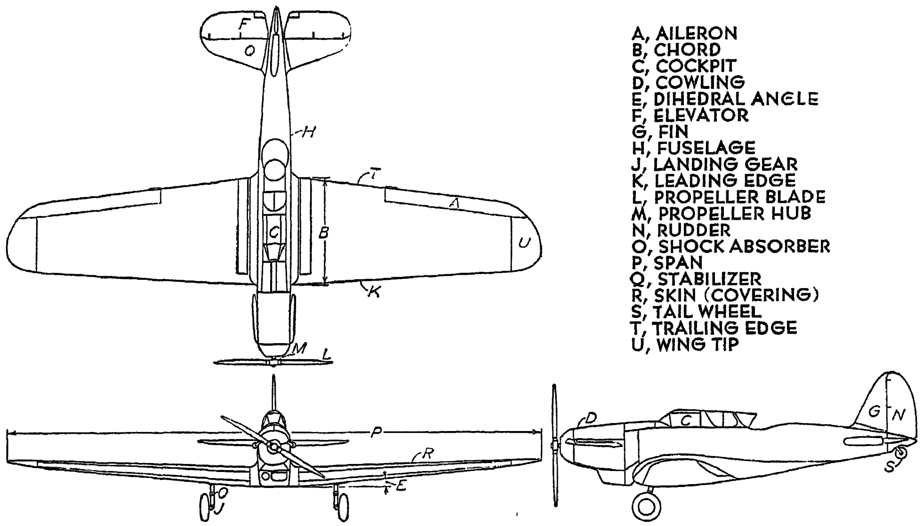


FIG. 904.—A three-view drawing, with names of parts added.

The diagram is generally made to small scale, and has on it the lofted or calculated dimensional data. As smaller or auxiliary portions of the plane are designed, the master diagram is consulted in order to get location dimensions correct and to ensure clearances.

Weight Estimate.—An accurate weight estimate of the various parts, obtained by mathematical calculation, is made as the design progresses, with alterations of the master diagram and related drawings as changes in weight or location occur.

378. Models.—Along with the design drawings, two kinds of models may be made for further study and visualization of the new design.

(1) **Wind-tunnel Model.**—When the general design of the plane has been decided upon, a wind-tunnel model is made and tested in order to check performance calculations.

(2) **Mock-up.**—A mock-up is a full-size model of the plane or, generally, of a portion of it, made for the study of the location of seats, equipment, pilot's controls and instruments, as well as for checking clearances. It is

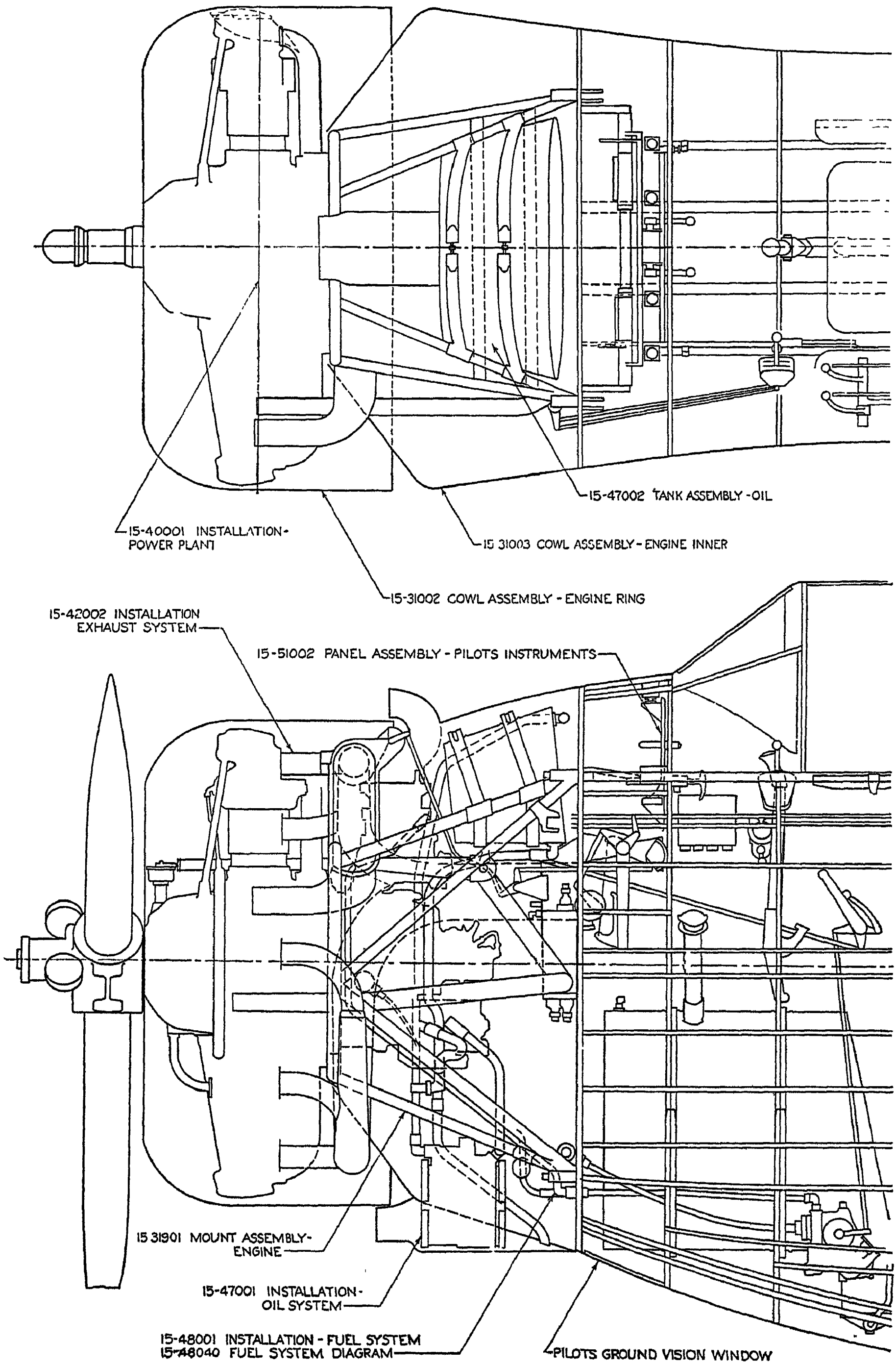


Fig. 905.—A portion of an inboard profile.

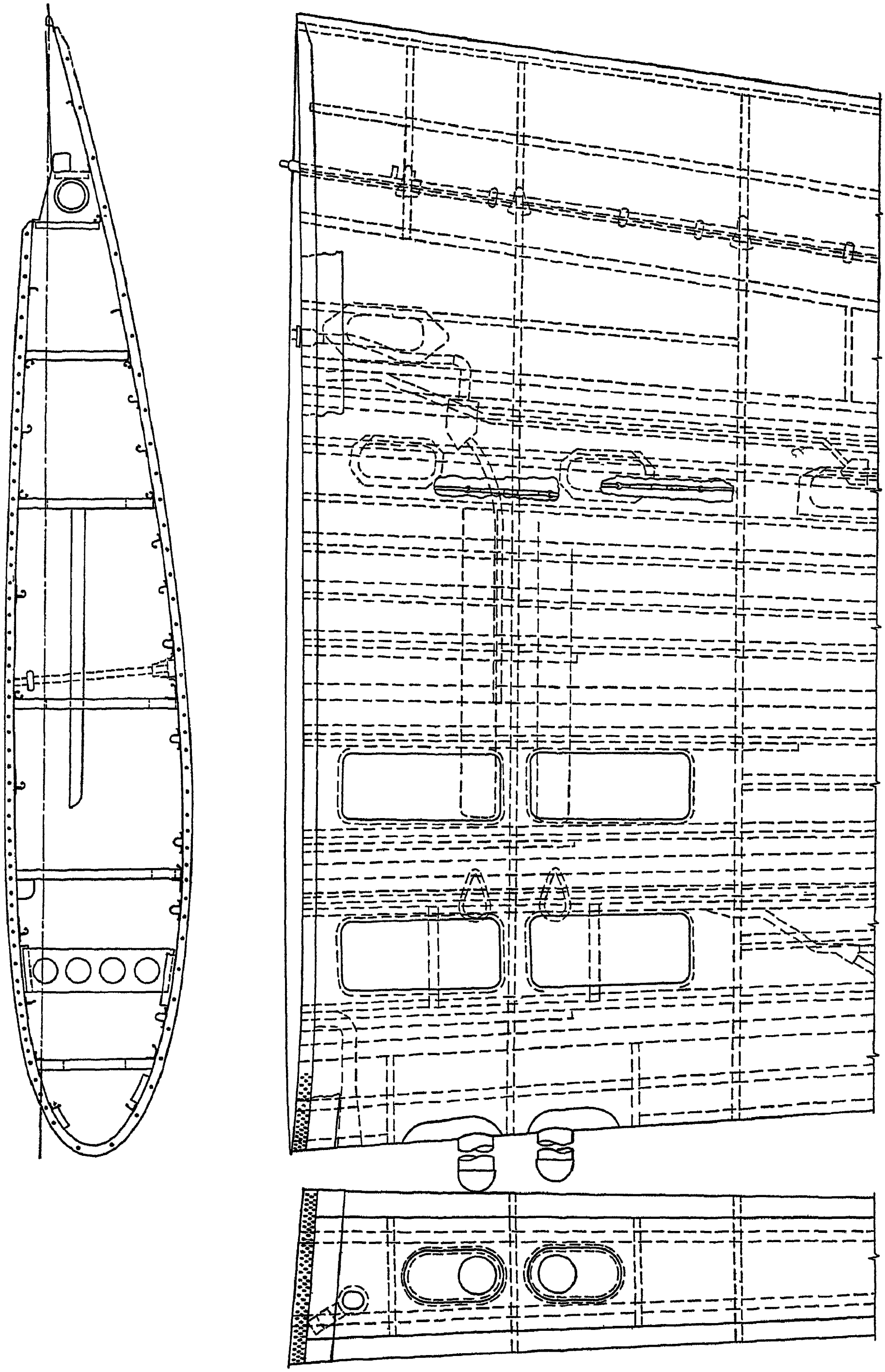


FIG. 906.— A portion of a wing drawing.

with the mock-up that the "feel" and arrangement of the controls is studied, and the location of all equipment for accessibility, convenience and efficiency is made. When production is actually started, a more nearly complete mock-up is built for final study and checking.

379. Layout Drawing.—Fuselage, wings, tail, landing gear and auxiliary equipment must be laid out to large scale with great care and accuracy. This work is very important and is done by the more experienced men. All members of the structure must be carefully shown so that connections may be perfect and so that all auxiliary equipment will fit into the main structure. The information that may be needed in making detail drawings is carefully considered when working on the layout, and all special materials, heat-treatments and fits are noted.

380. Production Drawings.—The meaning of the term "production drawings" is the same as "working drawings," and may be further classified as (*a*) detail, (*b*) assembly and (*c*) installation drawings. In general the principles of working drawings as given in Chap. XIV are followed in the aircraft industry. One exception to present standard drawing practice is the almost universal aircraft practice of making all dimensions read horizontally, whatever the direction of the dimension line. This method is specified by the U.S. Army Air Corps. and is justified by the large average size of airplane drawings.

381. Lofting.—Detail drawings of sheet-metal parts are sent to the lofting department, where the procedure is to make very accurate full-size layouts, from which templates can be made. Many dimensions, impossible to calculate, are determined for the engineering departments, thereby augmenting mathematical with graphical data. Accuracy is of such prime importance that drawing paper cannot be used because of its expansion and contraction. The first loft drawings were laid out on portions of the shop floor painted white for the purpose. Later they were done on thin laminated-wood drawing boards. Modern practice is to use enameled aluminum sheets with finished edges and rounded corners, which can be handled and stored readily and on which lines as fine as though made by an engraver are drawn with an 8H or 9H pencil sharpened to an extremely sharp point (sometimes the lines *are* engraved with a steel point). Honed plate glass has also been used for loft drawings. A successful attempt has been made to save lofting time through the use of photographic enlargements made with special lenses and equipment.

No T-squares are used in lofting. An accurate datum line is drawn the length of the sheet, and perpendicular offsets are constructed from it. Curves are drawn by first plotting points and then very carefully lining up a spline, held with weights or "ducks," to guide the pencil and pen. After the drawing is satisfactory in pencil it is inked on the aluminum sheet with a very fine line. Colored ink is used to indicate and separate various parts of the work. Figure 907 shows a portion of a loft drawing.

382. Fairing.—To "fair," or streamline, means to make a curve or surface mechanically smooth, with no small reverse curves or humps. When tolerances are given with the statement that the curve or surface must "fair," it may be necessary to work more accurately than the permitted tolerance. Dimensions to plus or minus $\frac{1}{32}$ inch on consecutive points of the curve could produce humps, although a series of points might all be either plus $\frac{1}{32}$ or minus $\frac{1}{32}$ inch and the surface be smooth. After surfaces have been faired by the loft, alterations of the design and layout drawings may be necessary.

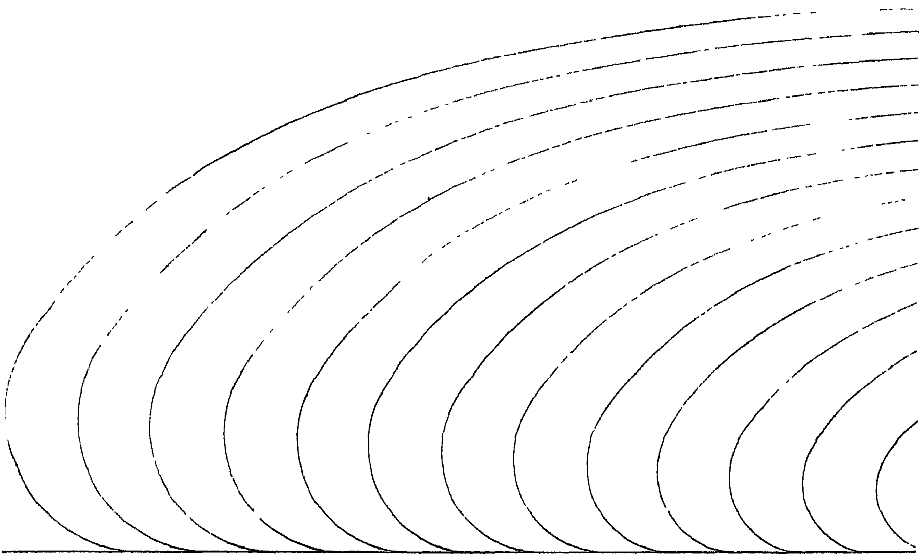


FIG. 907.—A portion of a loft drawing.

383. Naming of Drawings.—The U.S. Army Air Corps' standard practice is generally followed in the naming of aircraft drawings. The drawing title consists of the simplest basic name, followed by a dash and then further description of the part, for example, "PLATE—RETRACTING SCREW GUIDE." In reading the title the description is read first and then the basic name, thus: "Retracting screw guide plate." The basic name must never be abbreviated, and no commas are used. Basic names of more than one word are allowed in assembly-drawing titles, as: "BRACKET ASSEMBLY—PILOTS SEAT SUPPORT OUTER."

384. Drawing Sizes.—Drawing sizes in the aircraft industry follow the American Standard sizes, with some additional multiples. The U.S. Army Air Corps specifies $8\frac{1}{2}'' \times 11''$, $11'' \times 17''$, $11'' \times 34''$, $17'' \times 22''$, $17'' \times 42''$, $17'' \times 66''$, $22'' \times 34''$, $34'' \times 42''$, $34'' \times 66''$, $34 \times 88''$, $42'' \times 66''$, $42'' \times 88''$ and for larger drawings $36''$ or $42''$ by a length not to exceed $144''$ unless unavoidable. However, drawings as long as 50 feet are sometimes required. Large drawings and Van Dyke negatives are rolled

for filing, but blueprints are always "accordion" folded to $8\frac{1}{2}'' \times 11''$ size for filing and mailing, as in Fig. 908.

385. Zone Marking.—To facilitate the location of sections, dash numbers or other information on long drawings, the drawing is marked in "zones." The lower border is laid off in zones of 1 foot each, starting from the right-hand border and numbering toward the left. Each foot is marked by the proper numeral in a $\frac{1}{2}''$ square with its base coincident with the border line. Figure 909 shows a portion of a zone-marked drawing.

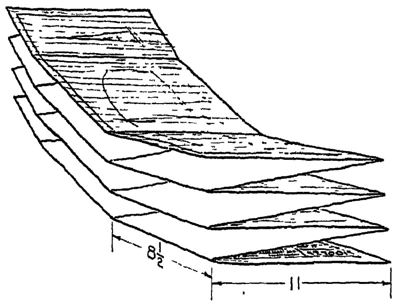


FIG. 908.—Accordion folding.

386. Scale of Drawings.—For large-scale drawings of single parts, subassemblies, etc., scales of full size, half size, quarter size and eighth size are standard. For all smaller scale drawings, such as three-view and proposal drawings, scales of $\frac{1}{20}$, $\frac{1}{30}$, $\frac{1}{40}$ and $\frac{1}{50}$ size are used. A civil engineer's scale may

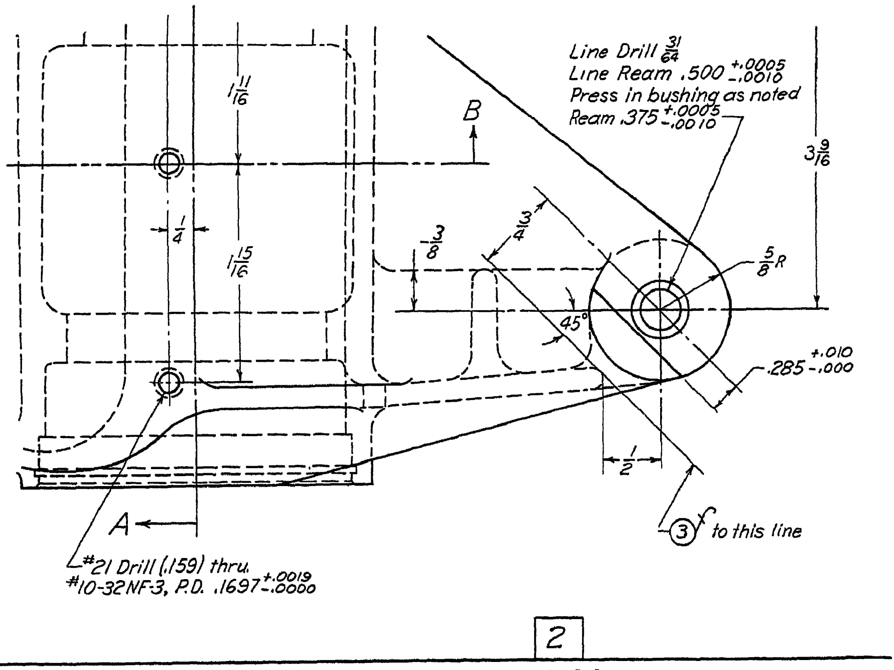


FIG. 909.—A portion of a zone-marked drawing.

be employed for these sizes, reading the scale as $\frac{1}{20}'' = 1''$ etc. Architects' scales of $\frac{1}{4}''$ or $\frac{1}{8}''$ to the foot *are not used* in aircraft practice. Full-size drawings are always preferred when possible.

387. Dimensioning.—In aircraft practice all distances are given in inches and the inch marks (″) are omitted. As one exception to this rule, wing span is sometimes given in feet. Figure 909 illustrates the practice, already mentioned, of placing all dimensions so as to read horizontally, or from the bottom of the sheet.

Either vertical or inclined capitals may be used in lettering notes and titles. All notes are placed horizontally.

388. Limits and Tolerances.—The usual tolerances specified in aircraft work are $\pm\frac{1}{32}$ on fractional dimensions for the general run of sheet-metal and fitting work; ± 0.010 on decimal dimensions for the average class of engine work, bolthole locations, and fits where great accuracy is not necessary; and $\pm\frac{1}{2}°$ for angular dimensions. Where very accurate fits are required the U.S. Army Air Corps' specifications for the determination of limits and tolerances should be followed. The ASA Standards (Limits and Tolerances for Cylindrical Fits, B 4a) are extensively used. See paragraph 182, Chap. XI.

389. Sectional Views.—Sections are treated as projected views wherever space permits (the section should be projected in third angle, never in first angle). On a removed section the correct angle and direction of rotation should be given.

390. Line Values.—For all accurate layout work and in lofting, a fine line must be used, made with a 4, 5 or 6H pencil in layout work, and with an 8H in lofting. For production drawings made on vellum or cloth, for reproduction, the outline must be bold and opaque, made with a pencil chosen from F, H, or 2H to fit the drawing surface, following general engineering practice.

391. Dash Numbers.—In order to identify the great number of parts used in the construction of aircraft, each part is designated by its drawing number, and when further identification is necessary a *dash number* is added after the drawing number. A dash number is simply a numeral prefixed by a dash to distinguish it from other numerals on the sheet, and it is placed in a $\frac{3}{8}$″ circle near the piece it identifies, with an arrow touching the outline of the part. It is followed by the name (noun only), material, and number required. See Figure 910. When dash numbers appear on any drawing other than their own, they are given in full with their drawing number, the circle being omitted as, 10127-1. On complicated drawings such as fuselage structures the encircled numbers point out all parts that are to be made from that drawing. The dash-number system, in general, is to be used only when the detailed parts of an assembly can be sufficiently dimensioned in their proper location on the assembly and is used to identify subparts of an assembly, subassemblies of a main assembly and parts permanently fastened together and used as a unit part.

392. Tabulated Drawings.—When two or more parts are covered by a single drawing and tabulated on that drawing, each piece should have a

dash number assigned to it, as the drawing number in this case is not a part number. The coding of parts which are similar but have one or more dimensions different is done by making a single drawing and giving each part a dash number of the basic drawing number.

393. Right- and Left-hand Parts.—Where right- and left-hand parts are required, a single drawing is made of the left-hand part and suitable notation placed above the title block as:

L.H. shown 00156-L
R.H. opposite 00156-R (Standard Air Corps practice)

Some companies deviate from this system, using even dash numbers for left-hand parts, and odd dash numbers for right-hand parts.

PART NO.	CABLE	NO. REQ.	A	MODEL	NEXT ASSEM.
170701-1	-2	2	45	AC-1	534891
170701-3	-4	2	40	AC-1	534891

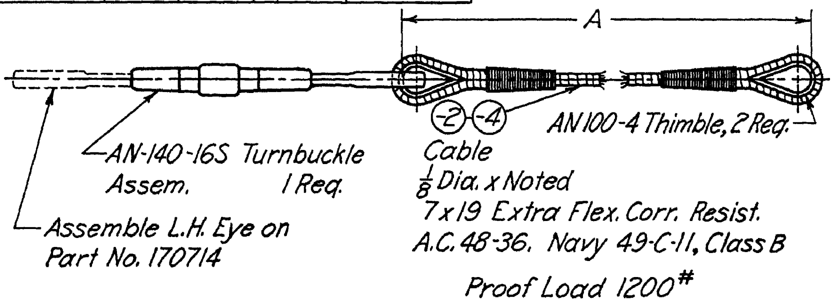


FIG. 910.—A dash-numbered drawing.

394. Standard Parts.—Wherever possible, standard parts that can be carried in stock should be used. Much unnecessary tooling is thereby saved. *Army-Navy Standard Parts* are those approved by the Standards Committee of both the Army and the Navy. Designation of these parts on assembly drawings requires prefixing the symbol *AN* to the part number, thus, *AN 671*. *Air Corps Standard Parts* (those without the *AN* prefix in the Air Corps Standard Parts book) should have the symbol *AC* prefixed to the part number. *Navy Standard Parts* (those without the *AN* prefix in the Navy Standard Parts Book) should have *NAF* (Naval Aircraft Factory) prefixed to the part number.

Commercial Standard Parts are any commercial parts usable without reworking. They are designated on assembly drawings by the manufacturer's part numbers or size designations.

395. Material and Process Specifications.—In the aircraft industry, materials, heat-treatments, finish, etc., are specified by giving Army, Navy or commercial specification numbers. The topic is beyond the scope of this chapter, but information is given in *Air Corps Material Specifications* and

Process Specifications, published by the Government and available to those directly concerned.

396. Joggling.—For structural shapes of aluminum alloy no joggle whose depth is greater than one-third its length can be made without danger of partially shearing the metal. See Figure 911. Flat sheets, however, may be joggled to the same depth in much shorter distance.

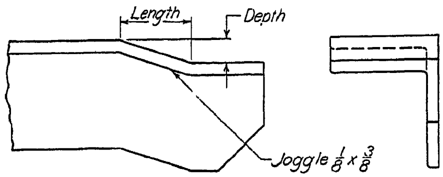


FIG. 911.—Joggling.

397. Bend Relief and Allowances.—Relief at the corners of bent plates is shown in Figure 912. In bending any sheet, allowance must be made for the thickness of the metal and its bending characteristics. Shop experience is an important factor, but bend allowance may be computed from the empirical formula $Z = (0.01745R + 0.0078T) \times$ No. of degrees of bend, as given in Figure 913.

398. Screw Threads.—The Army-Navy specifications for aircraft screw threads include the ASA Coarse Thread Series, *NC-2* and *NC-3*; Fine Thread Series, *NF-3*; and Extra-fine, *NEF-3*; along with the 8-, 12-, and

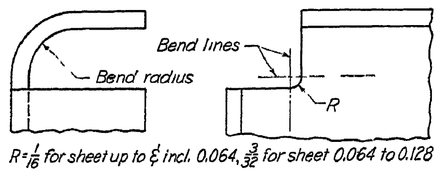


FIG. 912.—Bend relief.

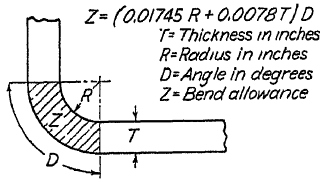


FIG. 913.—Bend allowance.

16-pitch Thread Series. All these are discussed in Chap. XII, and tables are given in the Appendix.

399. In this chapter the essential features of aircraft drawing have been explained. The general principles of engineering drawing all apply to this branch of engineering and may be found in the appropriate chapters of the book by consulting the index. For example, aeronautical maps would be under the chapter on maps and topographic drawings; rivets in the chapter on fastenings; etc.

PROBLEMS

400. In the following problems, aircraft practices in dimensioning, notation, specification, etc., should be followed. Dash numbers may be assumed. Paper 17″ × 22″ will be necessary for Prob. 3; 11″ × 17″ for the others.

1. The true fineness ratio of a streamlined shape is L/D where L is the outside length and D the outside width of the section. Draw the cross section of a streamlined tube having a fineness ratio of 2, $L = 10''$, and a wall thickness of $0.10''$. Round off the trailing end with a radius so that the actual length is 95 per cent of the $10''$ theoretical length. The table below gives coordinate dimensions in percentages of L and D. Use a civil engineer's scale in laying out this problem, full size.

Length, %	Width, %	Length, %	Width, %	Length, %	Width, %
0 0	0 0	20.0	91.1	65.0	80.1
1.25	26.0	25 0	95 9	70.0	73.2
2.5	37 1	30.0	98 6	75.0	65.3
5.0	52.5	35.0	100.0	80.0	56.2
7.5	63 6	40.0	99.5	85.0	46 1
10 0	72 0	45.0	97.9	90.0	33.8
12 5	78.5	50.0	95.0	95.0	19.0
15.0	83.6	55 0	91.0	100 0	0.0
17 5	87.0	60 0	86.1		

2. From the data given for Prob. I, make a cross-sectional drawing of a streamlined tube, length $15''$, fineness ratio 3, wall thickness 0.128.

3. Plot the airfoil shape given in the data following. Chord length, $100''$; scale, fifth size. The data give distances from chord line in percentages of chord length.

Chord, %	Upper	Lower	Chord, %	Upper	Lower
0.00	3.50	3.50	40.00	13.00	−1.60
1.25	5.98	1 43	50.00	11.99	−1.48
2.50	7 21	0.76	60.00	10.44	−1.29
5.00	8.86	−0.05	70.00	8.39	−1.04
7.50	10.01	−0.50	80.00	5.95	−0.73
10 00	10 89	−0.87	90.00	3.19	−0.39
15.00	12 17	−1.38	95.00	1.75	−0.25
20.00	12 96	−1.57	100.00	0.14	−0.01
30.00	13 35	−1.65			

4. Fig. 914. Detail drawing of aeronautical piston. Right half of end view to be a section on the center line of the piston pin. Top view and lower half of front view in section. Dimension completely, using standard aircraft practice in placement of dimension figures.

5. Fig. 915. Make detail drawings of parts of propeller hub, fixed-pitch-propeller type. To respect the wishes of the company, The Hamilton Standard Propeller Corporation, nominal dimensions only have been used instead of manufacturing tolerances.

6. Fig. 916. Assembly drawing of piston, master rod and articulated rod (baby rod) for Wright Whirlwind engine. In this problem, nominal dimensions only have been used instead of the manufacturing limits of the maker, and numerous details of design such as locking devices, lubrication ducts, etc., have been intentionally omitted, to simplify it as a drawing problem as well as to respect the wishes of the company in avoiding publication of detailed information on such a highly specialized product.

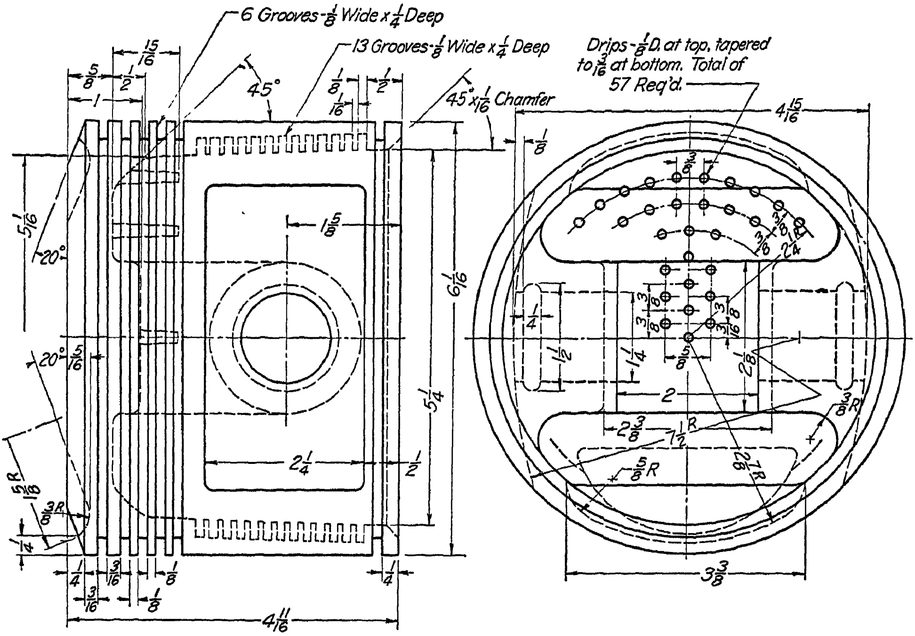


FIG. 914.—Aeronautical piston (Whirlwind) (see page 451).

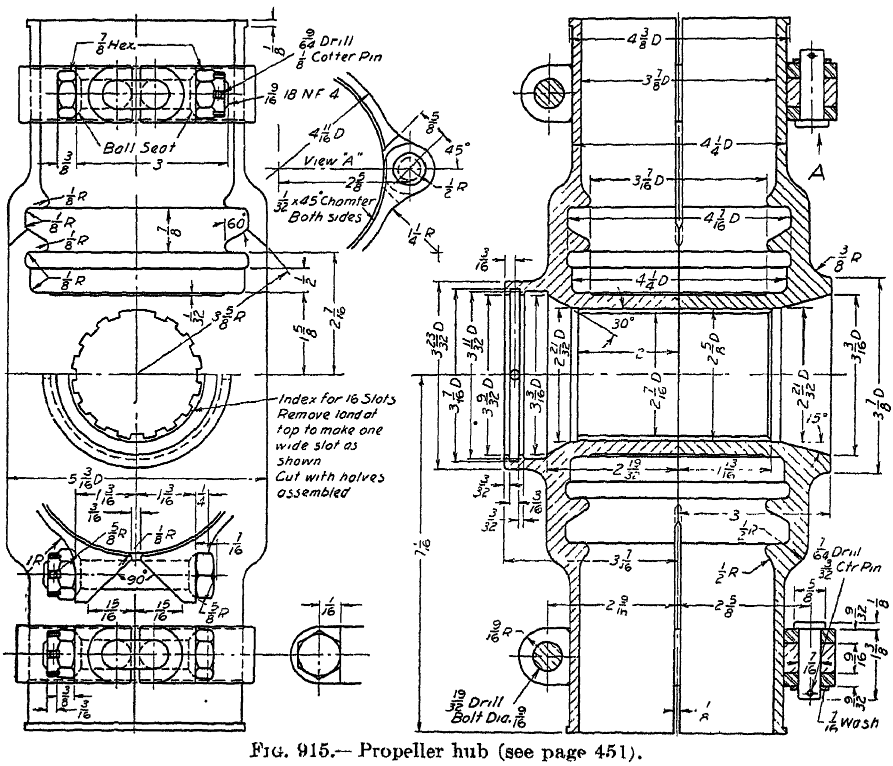


FIG. 915.—Propeller hub (see page 451).

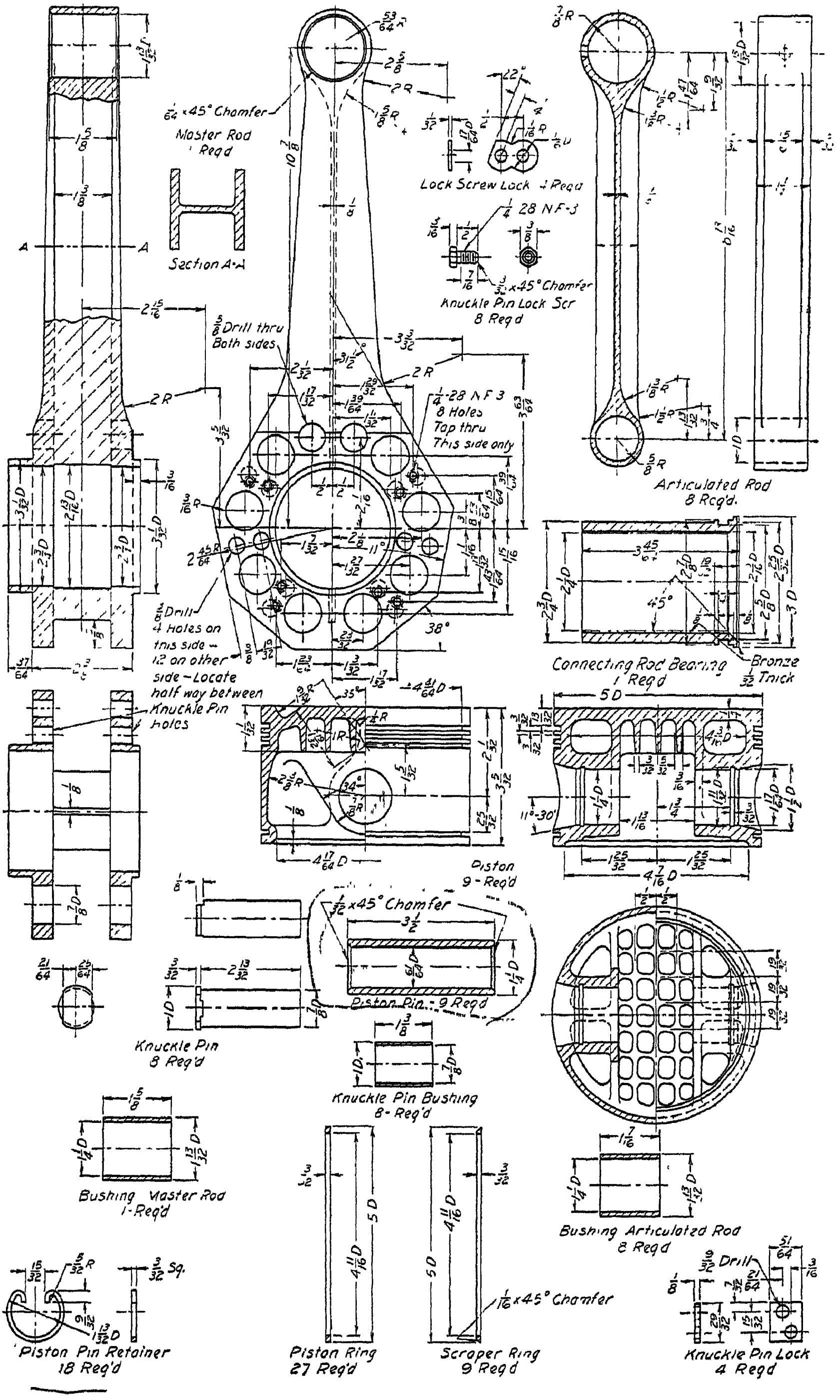


FIG. 916.—Piston and connecting rods, Wright Whirlwind engine (see page 451).

CHAPTER XXIV

THE ELEMENTS OF ARCHITECTURAL DRAWING

401. Architecture is classed as one of the fine arts, and it is entirely beyond the scope of this book to take up architectural designing. But in applying engineering drawing as a language, to architecture, the architect makes use of idioms and peculiarities of expression with which all engineers should be familiar, for in the interrelation of the professions they are often required to read or work from architects' drawings or to make drawings for special structures.

402. Characteristics of Architectural Drawing.—The general principles of drawing are the same for all kinds of technical work, but each profession requires its own special application of these principles and the employment of particular methods, symbols and conventions. In architectural drawing the necessary smallness of scale requires that the general drawings be made up largely of conventional symbols indicating the various parts. Also so many notes of explanation and information regarding material and finish are required that it is not possible to include all of them on the drawings, hence they are written separately in a document called the *specifications.* These specifications are complementary to the drawings and have equal importance and weight.

In the make-up of an architect's drawings there is evidence of artistic feeling, produced in part by the freehand work and lettering and in part by the use of finer lines, which gives them an entirely different appearance from that of a set of machine drawings. One peculiarity found in many architectural drawings is the overrunning of corners. This artifice in an experienced draftsman's work gives a certain snap and freedom, but this statement must not be taken by the beginner as a license for carelessness.

In arrangement of views, third-angle projection is standard American practice for all branches of drawing, although now and then an architectural detail is seen made in the first angle. Sometimes it is advantageous to use what might be called "second-angle projection," in which one view is superimposed over another. This is often done in stair detailing, as illustrated in Fig. 933.

Reflected Views.—A distinctively architectural feature is the "reflected view," occasionally used, in which the drawing, usually a part view, as of a soffit or ceiling, is made as if reflected in a mirror on the ground. It should not be confused with another architectural term, the "view looking up," often used to show the underface of a cornice, etc.

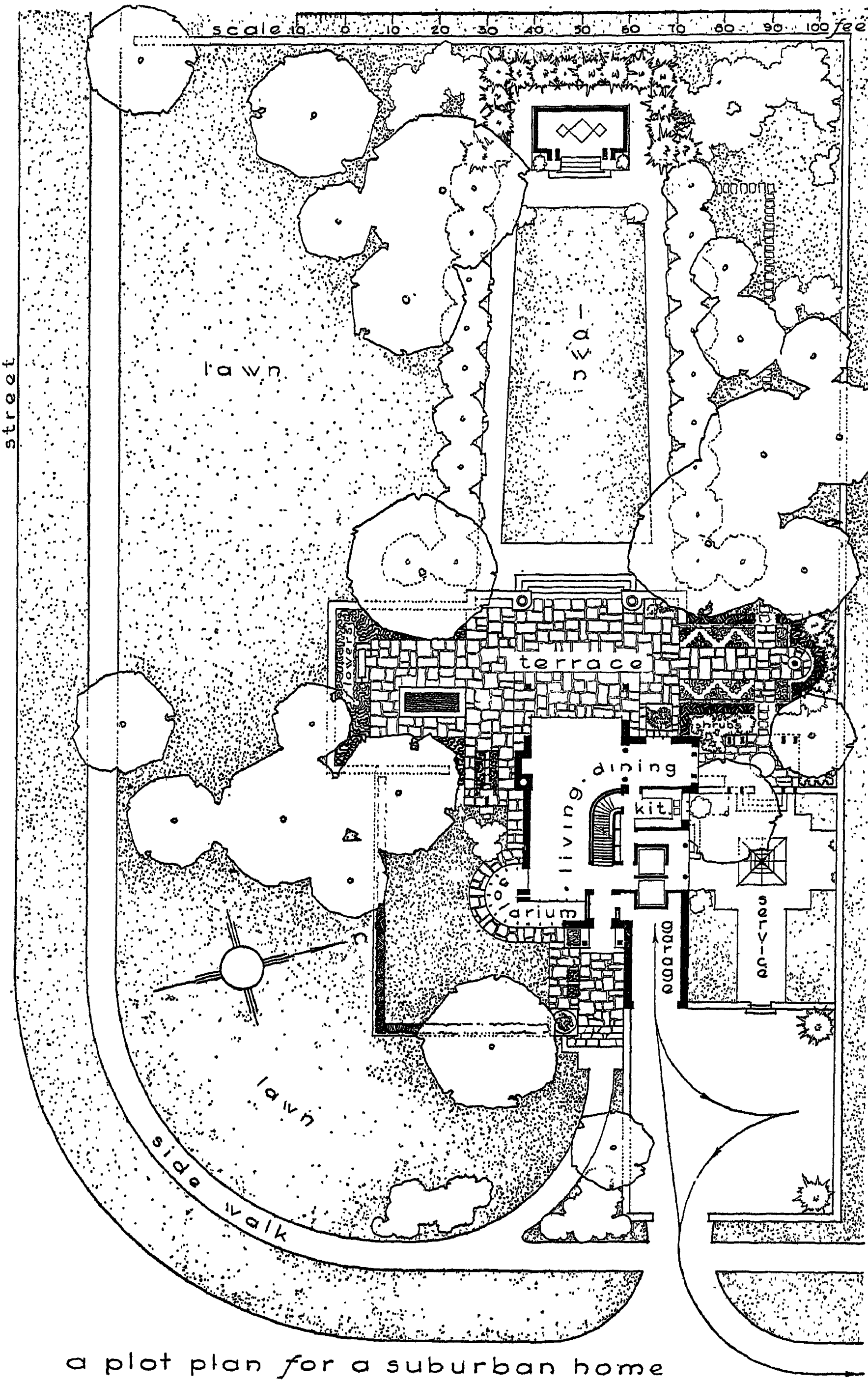
Profiling.—Another architectural drawing feature, shown in Fig. 933, is that produced by "profiling" or "silhouetting" the important outline with a heavier line than the other lines of the drawing. This aids the drawing greatly in both appearance and ease of reading. It is of particular value on sectional drawings, to bring out the sectional outline distinctly from the parts beyond the cutting plane.

403. Kinds of Drawings.—Architectural drawings may be divided into three general classes: (1) preliminary studies, (2) presentation drawings and (3) working drawings.

404. Preliminary Studies.—In an architectural project the first step taken, after a careful inquiry into the owner's demands, function of the building, materials of construction and character of the site, consists in the making of a program embodying all the necessary requirements for the proposed building. As the designer studies the various conditions and requirements as outlined in the program, the problem begins to take form, and the ideas first find expression in rough sketch studies. Such studies are usually made with soft pencil on tracing paper, as one sketch may be made over another, thus saving time in the layout and enabling the preservation of all the different solutions. They are free, spontaneous drawings indicating the composition of the required elements. A favorite expression of one of our able architects is, "keep the idea fluid at this stage." Many variations are studied in this form, and eventually one is selected as the *parti* or scheme for the design of the building. From this stage the preliminary drawings of plans, elevations and often perspectives are developed, to describe the proposed scheme more fully for approval by the owner. They are made on tracing paper and are often mounted for display. For effectiveness they are sometimes rendered in color.

405. Presentation Drawings.—The object of presentation drawings is to give a realistic and effective representation of the design of a proposed building for illustrative or competitive purposes. They may consist of plans and elevations or, to be more thorough, may include perspective drawings, but in either case they will contain little or no structural information. For legibility and attractiveness they are generally rendered in water color, pen and ink, crayon or pencil, giving the effect of color, light and shade. Such accessories as human figures, adjacent buildings, foliage, etc., are often introduced in elevations and perspectives not so much for pictorial effect as for *scale*, an idea of the relative size of the building.

In rendering plans for display or competitive purposes, shadows are often used to show the plan in relief. The terms "poché" and "mosaic" are used in connection with this type of drawing, poché meaning simply the blackening of the walls to indicate their relative importance in the composition, and mosaic the rendering in light lines and tints of the floor design, furniture, etc., on the interior and the entourage of walks, drives and planting on the exterior, representing the grounds immediately surrounding the building.



a plot plan for a suburban home

FIG. 917.—A presentation drawing.

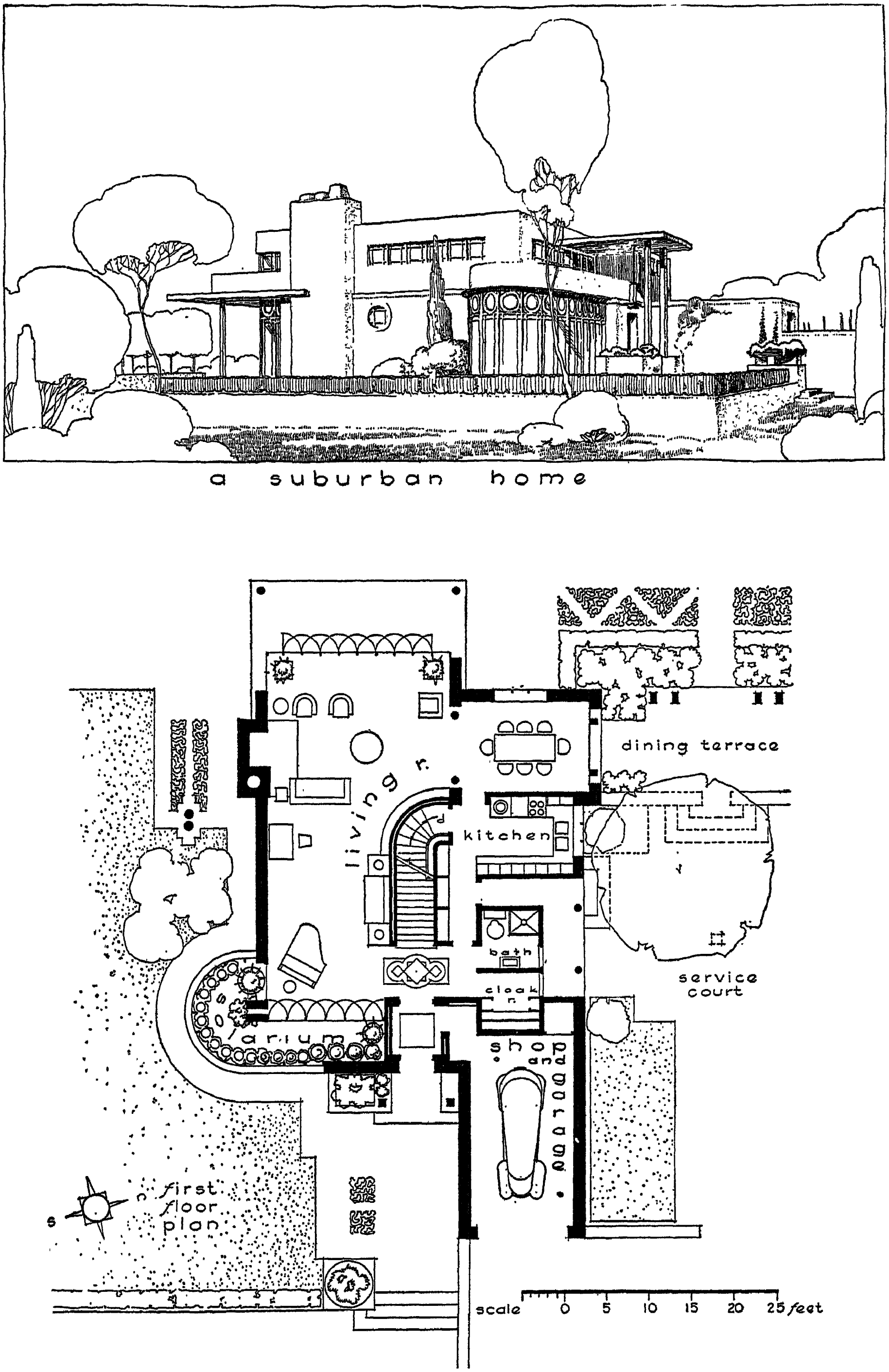


FIG. 918.—A presentation drawing.

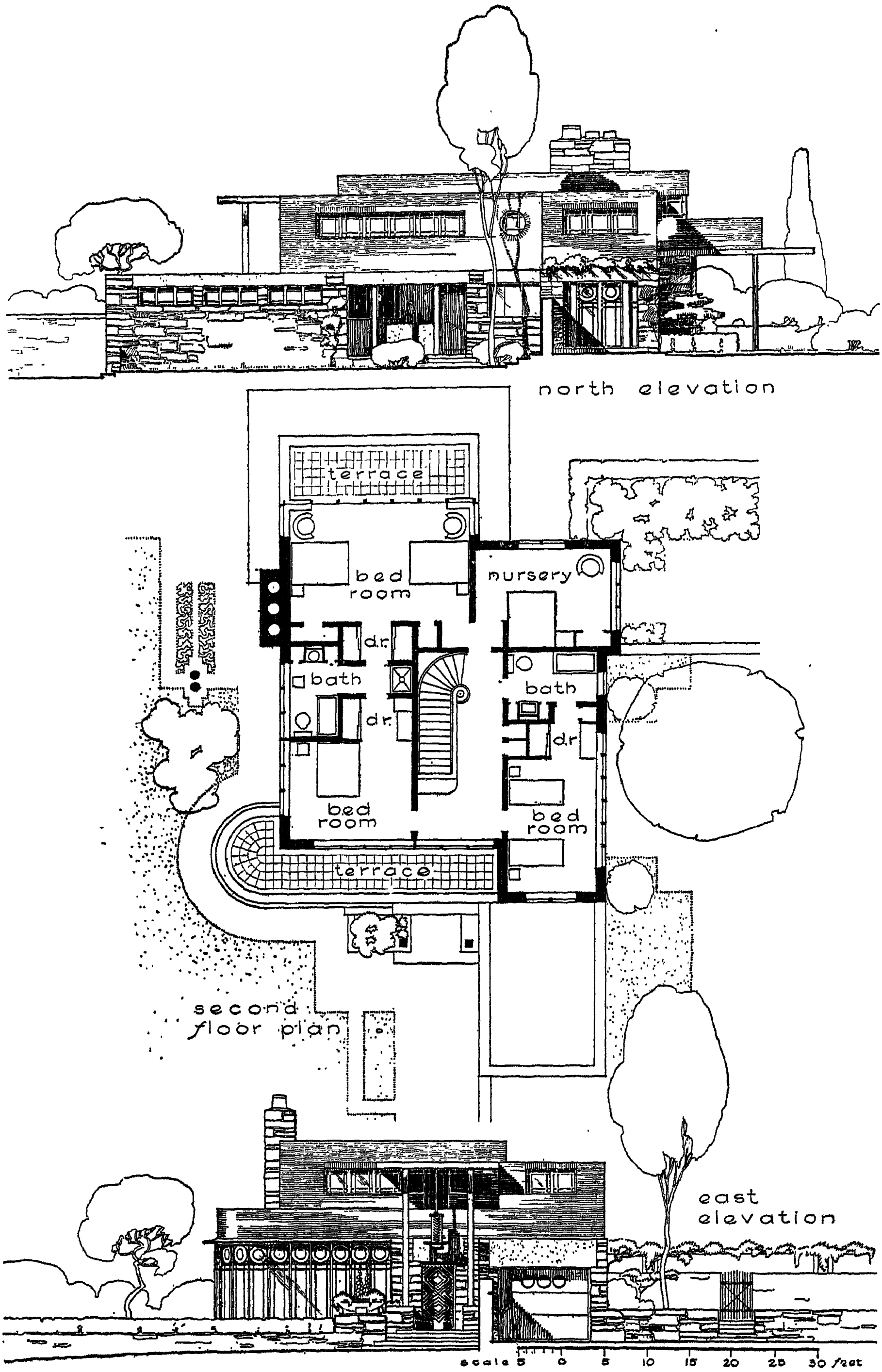


FIG. 919.—A presentation drawing.

Frequently in a symmetrical room one half is shown with a floor mosaic and the other half with the ceiling mosaic as a reflected view. A pen-rendered plot plan is shown in Fig. 917. Figures 918 and 919 are presentation drawings of the plans and elevations of the same house.

406. Models.—There is an increasing use of models for proposed buildings. Formerly the work of modelers in plaster of paris, these are now made in the drawing room, using drawing paper and cardboard, and far excel the white plaster model in giving a greatly increased effect of realism in color and texture. The advantage of such a model in showing the appearance of the completed building and the perspective effect from any angle is of obvious value both to the designer and to the client. In making paper models the different walls and roofs are laid out in developed form and then rendered, folded and mounted on a board base. The particularly important point to observe is that all features, such as moldings, railings, planting, etc., be kept to scale. Much artistic ability may be evidenced in their construction, and the ingenuity of the modeler is exhibited in the use of various materials in the entourage. Tinted sponges for trees, rubber sponge for hedges and shrubbery, sawdust and sand in glue, and various other accessory material will be thought of. For reproduction purposes, a photograph of the model is used instead of a perspective drawing, sometimes superimposed on one of the site, with adjacent buildings, made at the same angle.

407. Working Drawings.—Under this term are included *plans*, *elevations*, *sections* and *detail drawings*, which, taken with the *specifications* for details of materials and finish, give the working information from which to execute the contract agreement and erect the building. Their first use is by the contractors in estimating for bids.

All the general principles of Chap. XIV regarding working drawings are applicable to architectural working drawings. The assembly drawings are usually made with only one plan or elevation on a sheet, in order to keep the drawings to convenient working size. The most frequent scale used on these drawings is $\frac{1}{8}'' = 1'$, or, as often expressed, "1 inch equals 8 feet." For small buildings, perhaps up to 60 feet long, $\frac{1}{4}'' = 1'$ is used.

As a general rule, things which are related should be shown together and information concerning each craft should be grouped, so far as possible. Many present-day buildings are so complicated that it is advantageous to draw special plans for each of the several crafts, in addition to the general plans, as for structural steel, heating, plumbing and wiring.

In making working drawings the draftsman must be familiar with local and state building codes, and the legal requirements as to approval, permits and restrictions.

408. Plan of Site.—Before designing any structure of importance a site plan is made, giving the property line, contours, available utilities (sewer, gas, water), location of trees and other features. The building is then designed to fit the site. This drawing is completed by locating on it the

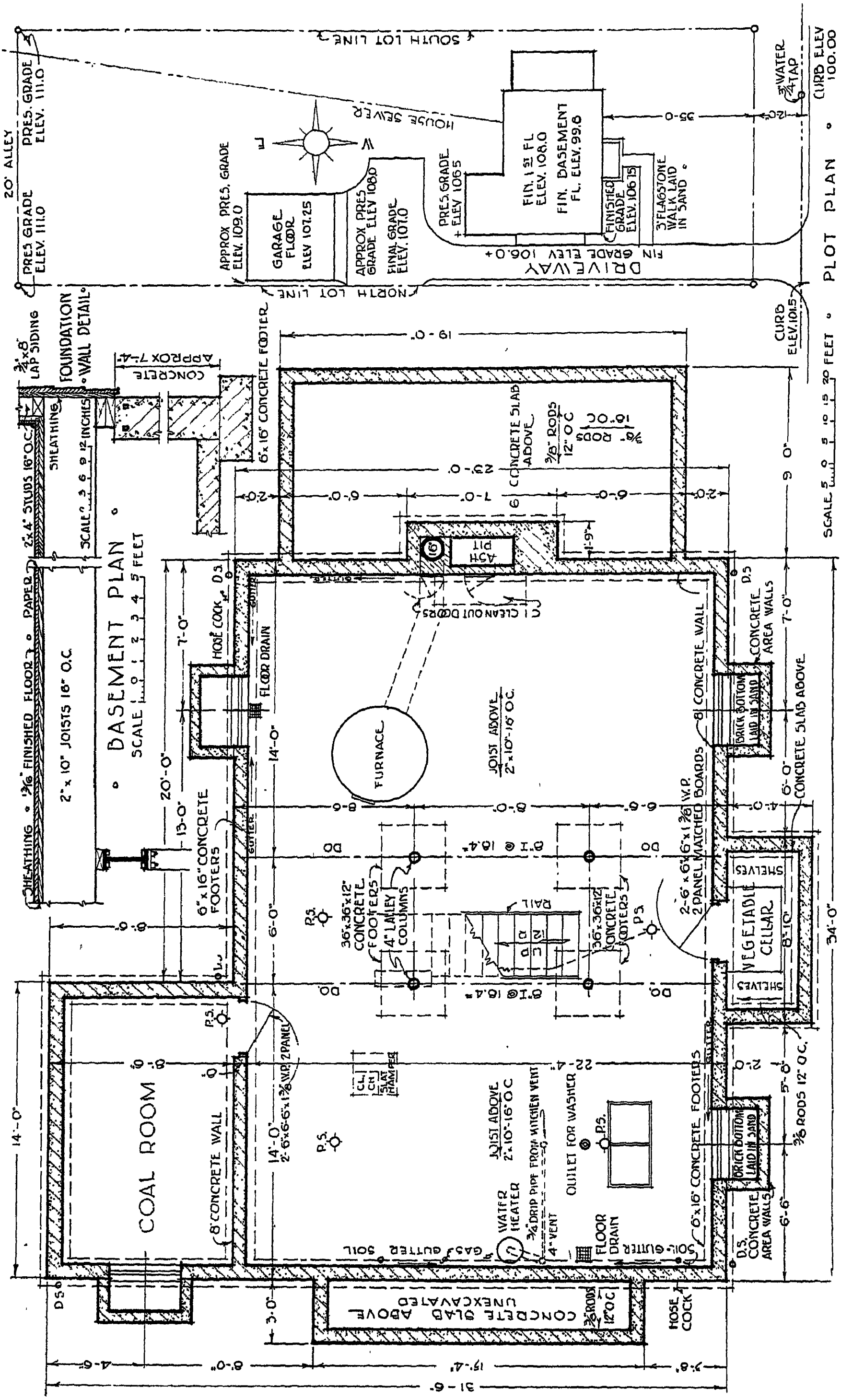


FIG. 920.—Working drawing; basement plan and plot plan.

building, approaches and contours of finished grades. For an ordinary residence, dimensions placed on the basement plan showing the distances of the building from the lot lines usually fulfill building-permit requirements.

409. Floor Plans.—Figs. 920, 921, 922. A floor plan is a horizontal section at a distance above the floor varying so as to cut the walls at a height which will best show the construction. The cut will thus evidently cross all openings for that story, no matter at what height they are from the floor. On account of the small scale compared with the actual size of the building, plans are largely made up of conventional symbols, with notes referring to detail drawings of different items. Walls, doors, windows, fixtures, etc., are all indicated by conventional representation, using symbols which are readily understood by the contractors who read the drawings. A floor plan contains, in general, the information for the space between the floor represented and the floor above, even though some items noted are above the cutting plane. The plan will show the location of all doors, windows, partition walls, radiators, built-in fixtures, ducts and flues, outlets for lighting and heating, material of floor, and information concerning the ceiling above, as beams, light outlets, etc. The joist framing of the floor above is indicated except when separate framing plans are necessary. The framing of a simple building is usually left to the contractor. In the case of special framing for heavy or concentrated loads, such as mill buildings, separate framing plans are drawn showing all the details of construction. A separate plan might be needed also for location of and foundations for machinery.

410. Drawing a Plan.—A plan is always laid out with the front of the building at the bottom of the sheet. After selecting the scale ($\frac{1}{4}'' = 1'$ for ordinary house plans), draw and measure a line representing the outside face of the front wall. If the plan is symmetrical, draw the main axis. The axes of a plan correspond to the center lines of a machine drawing and have a very important place in design. Complete the exterior walls and interior partitions (frame walls are drawn 6″ thick, brick walls 9″, 13″, 17″, etc.), then locate stairways, doors and other interior construction. In drawing the stairway, first make a diagram to find the number of steps and space required (for this the architect always uses the scale as shown in Fig. 131). The rise, or height from one step to the next is between $6\frac{1}{2}$ and $7\frac{1}{2}$ inches, and the tread is so proportioned that the sum of rise and tread is about $17\frac{1}{2}$ inches. One well-known rule makes the tread plus twice the rise equal 25 inches. On the plan the lines drawn represent the edges of the risers and are as far apart as the width of the tread. The entire flight is not drawn on the plan but is stopped about halfway up so as to show what is under it. Each floor plan thus shows part of the stairways leading both up and down from the floor represented. Always indicate the direction and number of risers in the stairway by an arrow and note (as in Fig. 921). The windows are not drawn until the elevations have been designed, but if their position in the wall is known their center lines are indicated. The first floor plan is

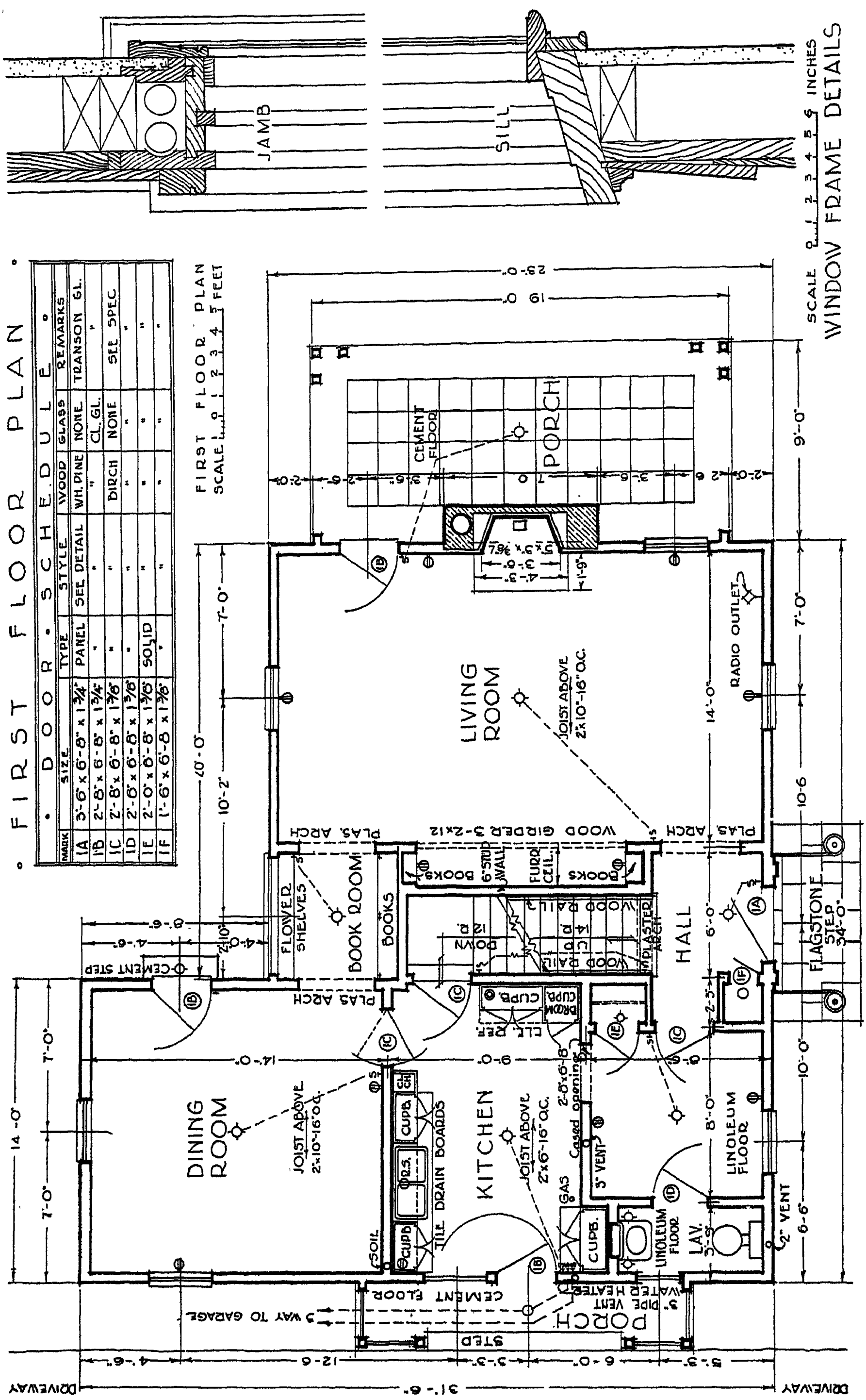


Fig. 921.—Working drawing; first floor plan and window detail.

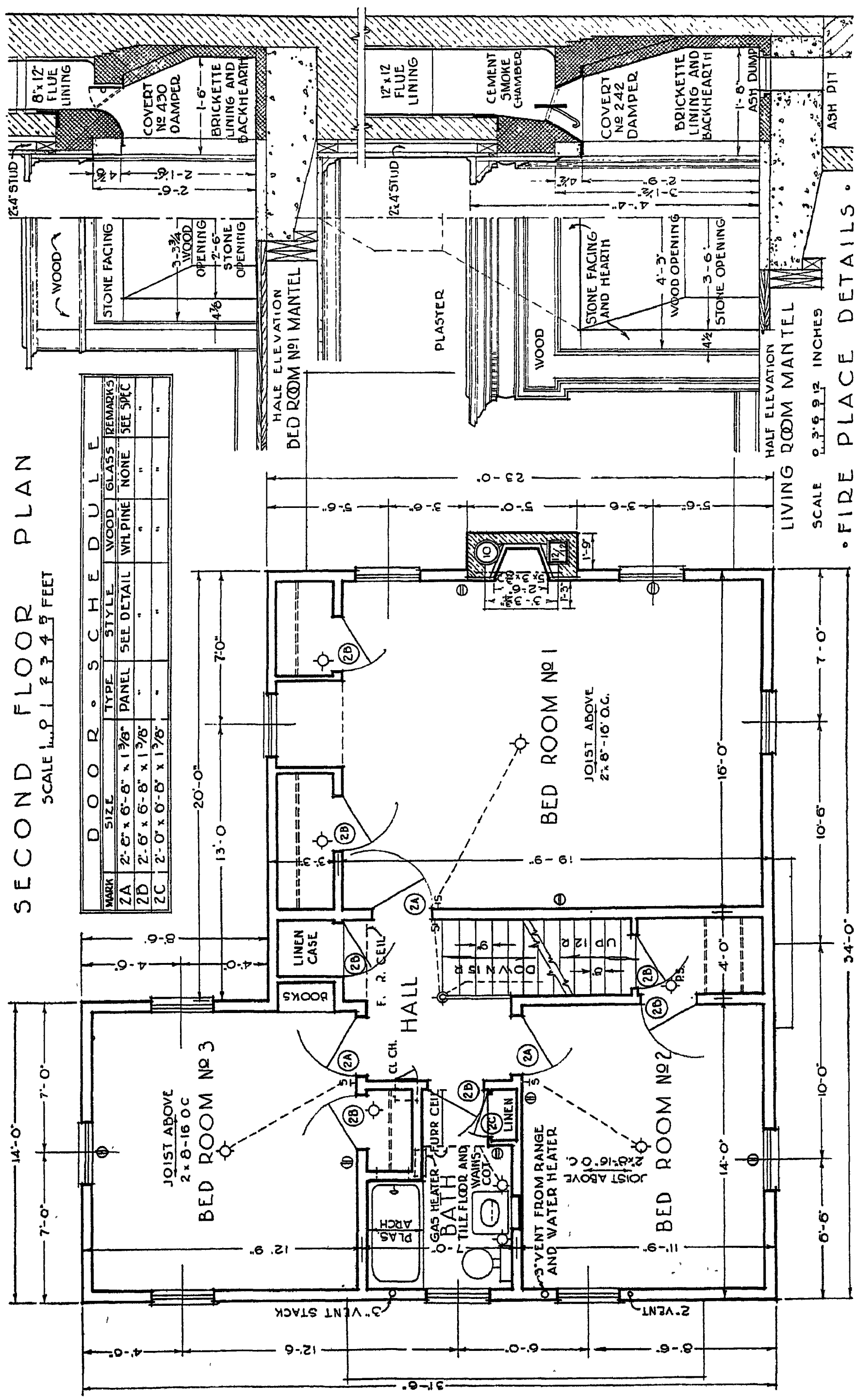


FIG. 922.—Working drawing; second floor plan and fireplace detail.

usually made first, and the outlines for basement plan, second floor plan and roof plan traced or drawn from it.

411. Elevations.—An elevation is a vertical projection showing the front, side or rear view of a structure. When a plan is irregular, other elevations parallel to the walls are necessary. The elevation gives the floor heights, openings and exterior treatment. The visualizing power must be exercised in imagining the actual appearance or perspective of a building from its elevations. Roofs in elevation are thus often misleading to persons unfamiliar with drawings, as their appearance in projection is so different from their real appearance on the building when finished. Figures 923 and 924 illustrate what features are shown and what dimensions are given on elevations. The garage and workshop, Fig. 925, shows the typical treatment of plan and elevation of this class of buildings.

412. Drawing an Elevation.—First draw a wall section at the side of the sheet, starting with the foundation and showing grade line, floor heights, sill and head of windows, cornice and pitch of roof and thickness of walls. Carry the grade line across the sheet as the working base line. Project the floor and ceiling lines across lightly. With the plan sheet placed above the elevation, project down for widths. Locate the windows and complete the elevations as shown in the figures.

413. Sections.—A general section is an interior view on a vertical cutting plane to show interior construction and architectural treatment. This cutting plane need not be continuous but, as in the case of the horizontal, may be staggered so as to include as much information as possible. In a simple structure a part section or "wall section" shown with the elevation, either to the same scale or larger, is often sufficient to give the required vertical dimensions. Part sections to larger scale are often used in connection with drawings, as, for example, in Figs. 921, 922 and 924, the usual cutting-plane line indicating the location and direction of the sectional view.

414. Detail Drawings.—A set of drawings will contain, in addition to the plans, elevations and sections, larger scale drawings of such parts as are not indicated with sufficient definiteness on the small-scale drawings. Stair details and detail sections of various items, such as footings, windows, framing, etc., may be shown clearly to the scales of ¾″ or 1½″ to 1′. Details are best grouped so that each sheet contains the references made on one sheet of the general drawings.

As the building progresses, the drawings are supplemented by full-size drawings of moldings and millwork details, ornamental iron, etc., usually made in soft pencil on tracing paper and blueprinted, all of which must be checked carefully by measurements on the building. In these drawings, revolved sections are used freely.

Figure 933 illustrates a method of combining views, superimposing a plan view on an elevation, that is sometimes used for saving space and for convenience in projecting one view from the other.

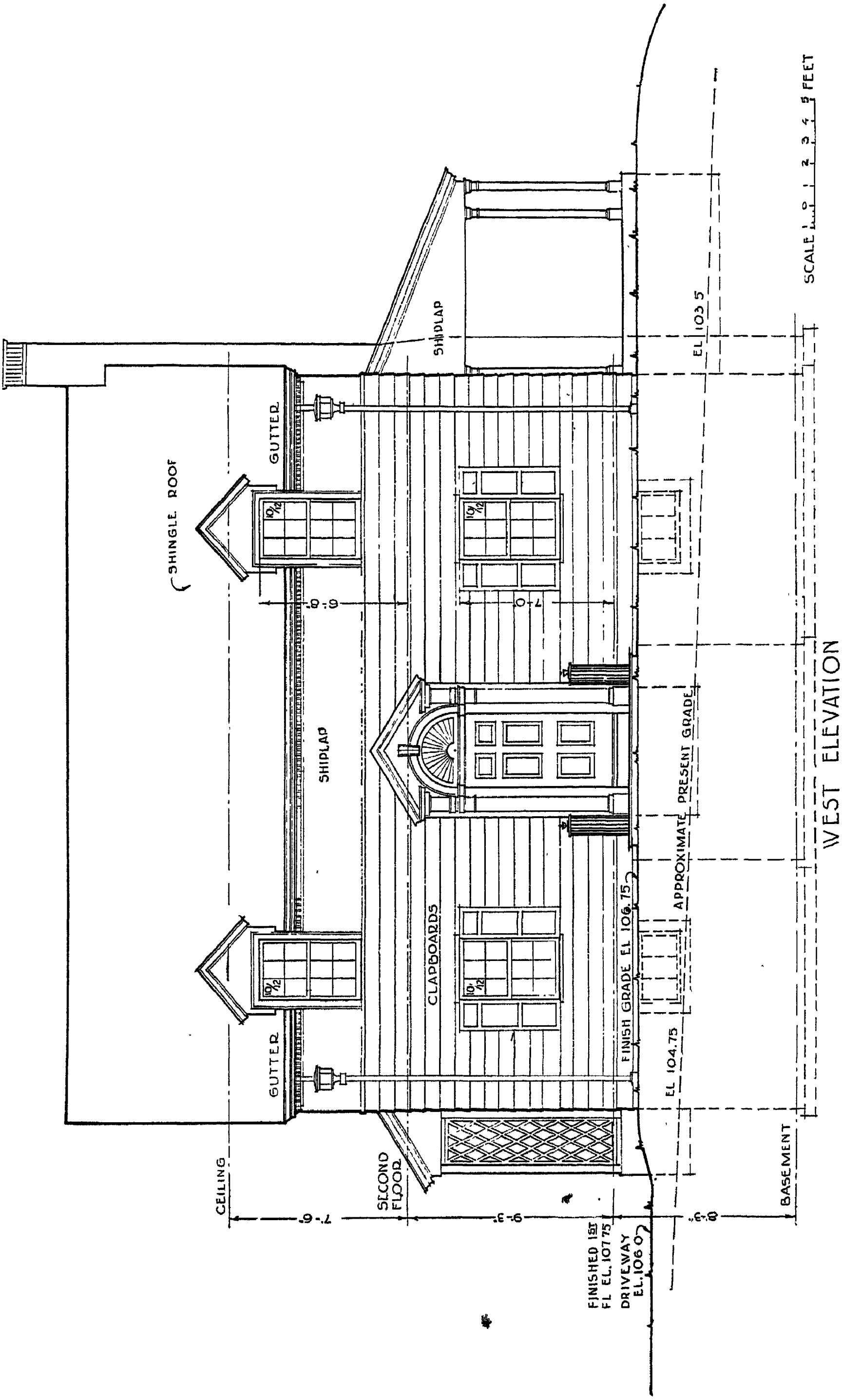


FIG. 923.—Working drawing; west elevation.

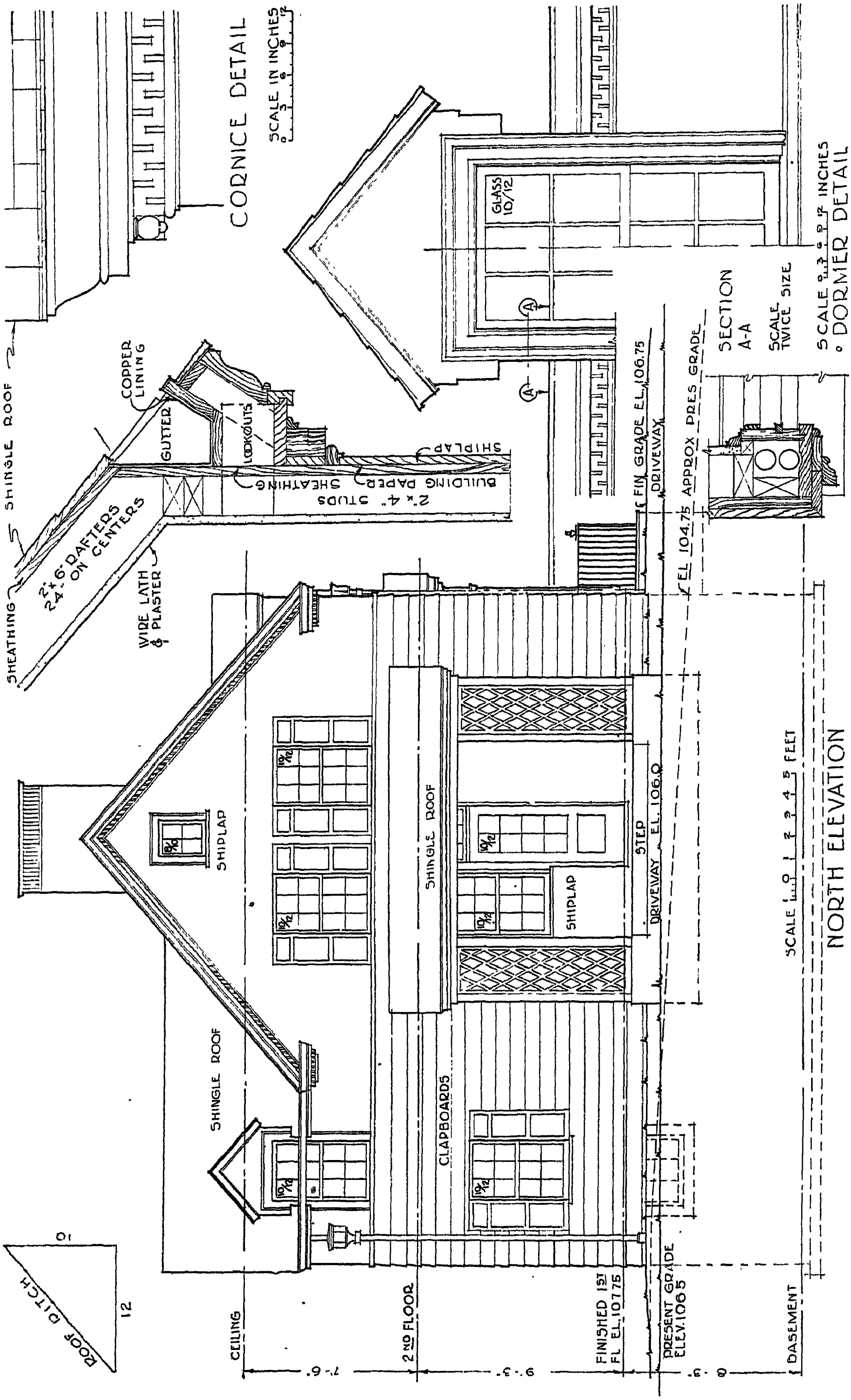


FIG. 924.—Working drawing; north elevation and details.

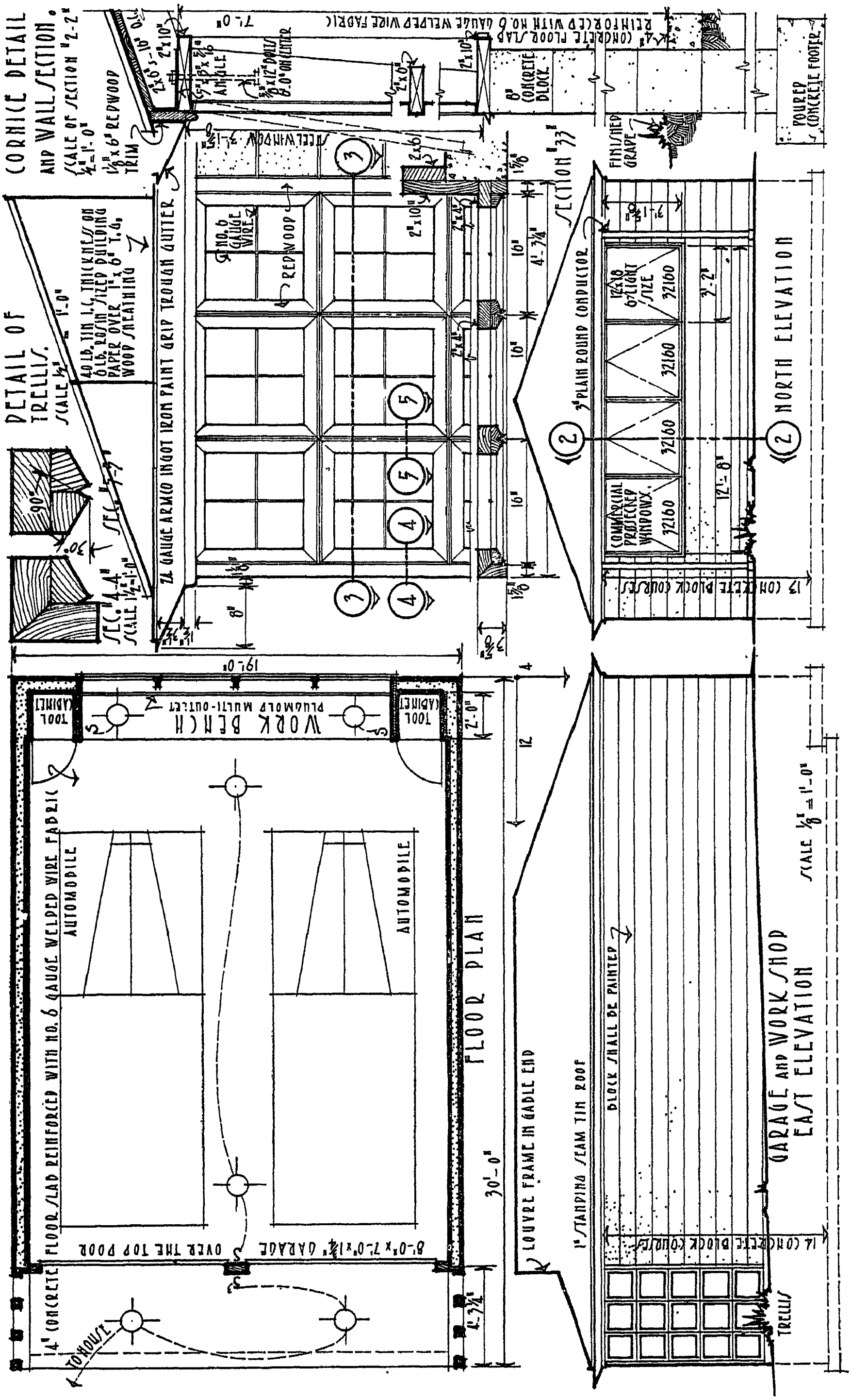


Fig. 925.—Garage and workshop.

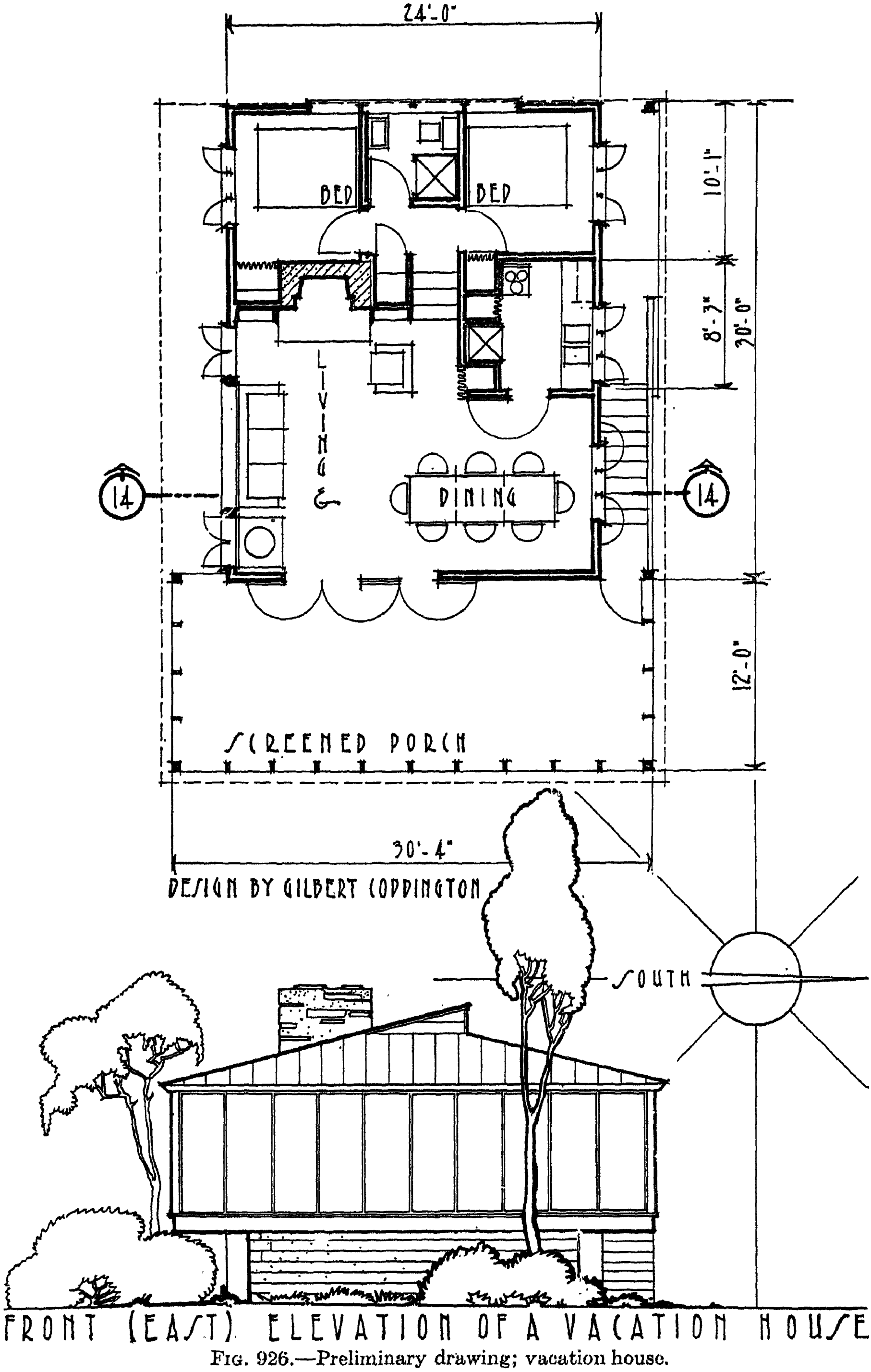


FIG. 926.—Preliminary drawing; vacation house.

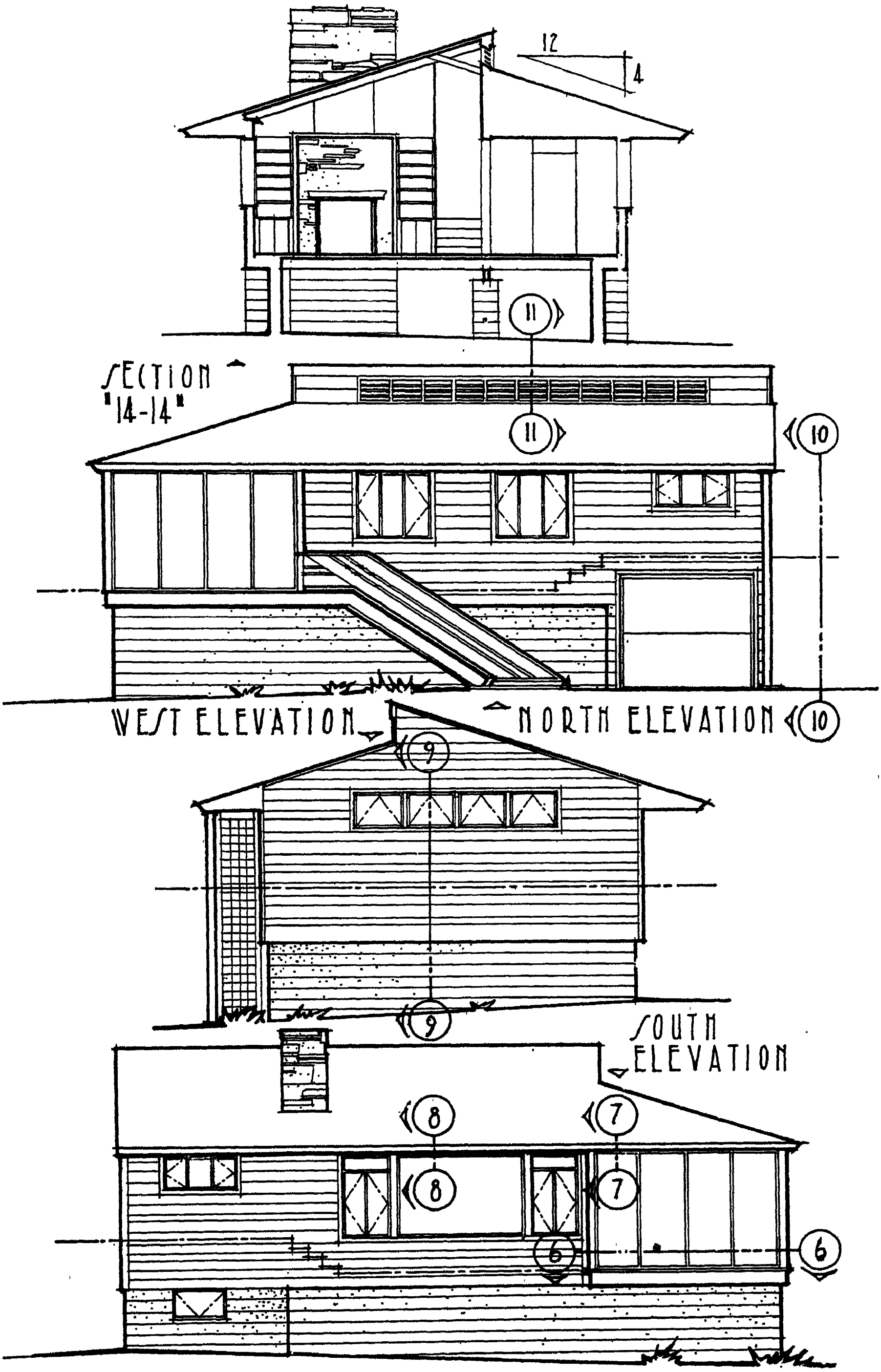


FIG. 927.—Preliminary drawing; vacation house.

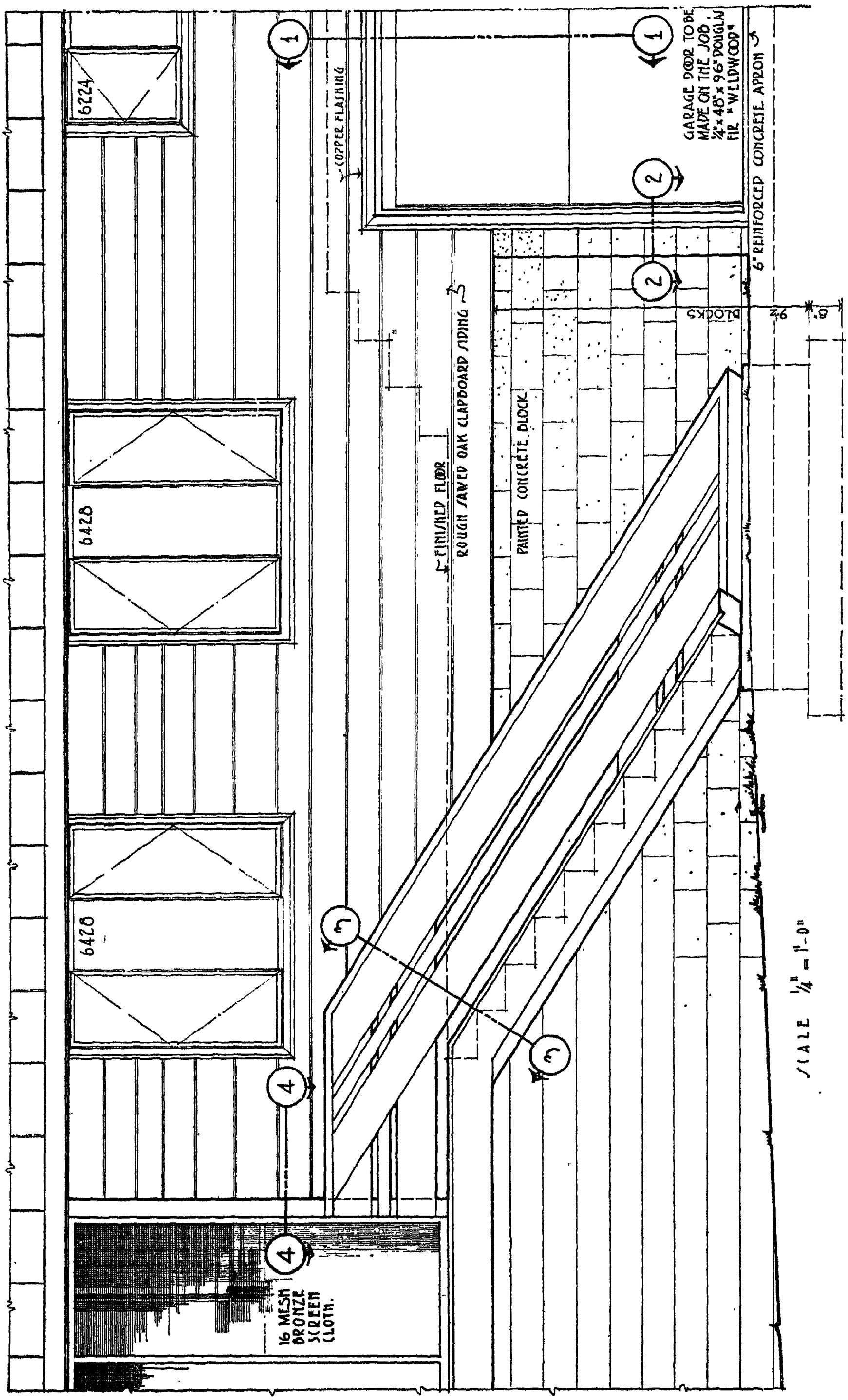


FIG. 928.—Detail elevation.

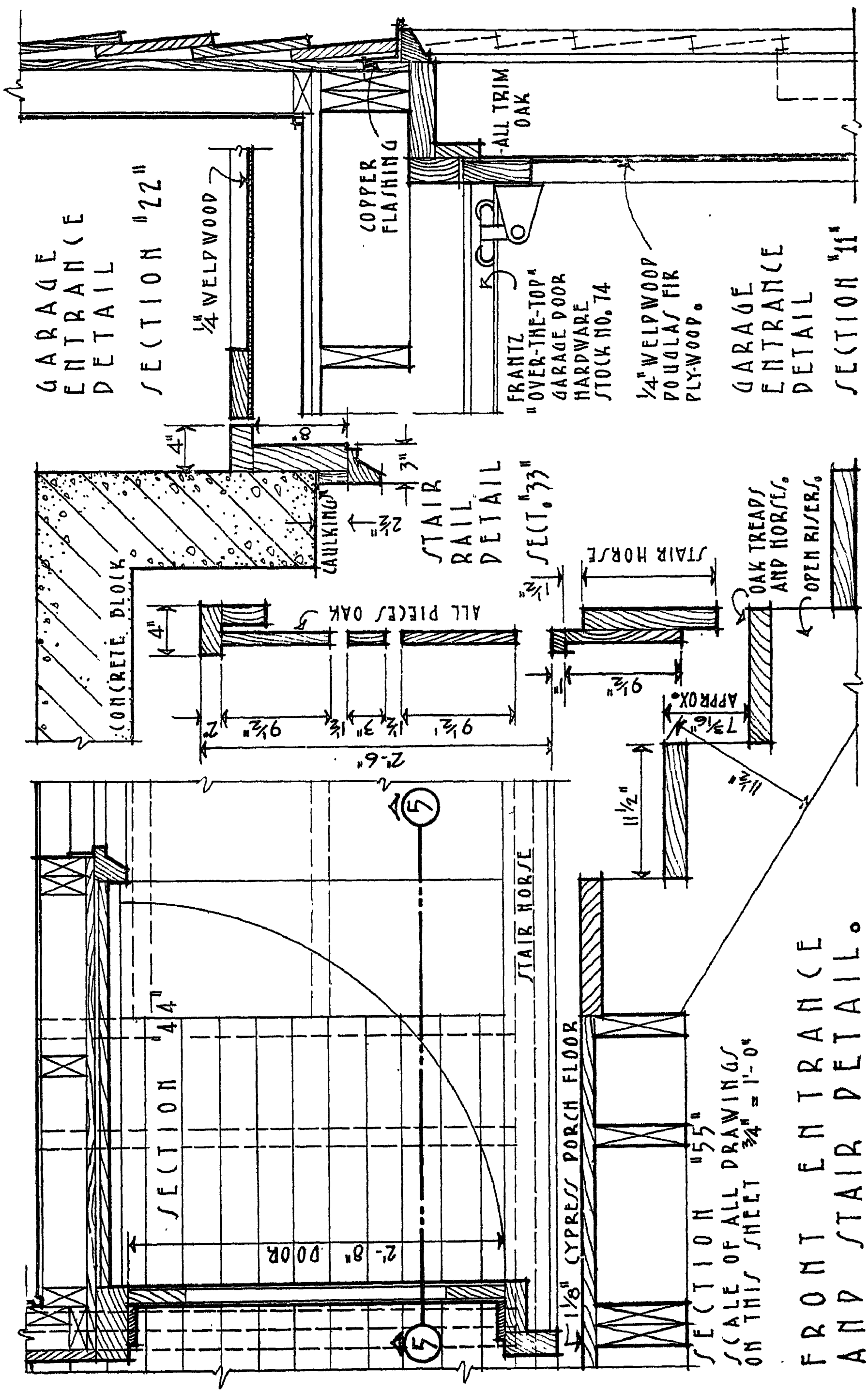


Fig. 929.—Construction details.

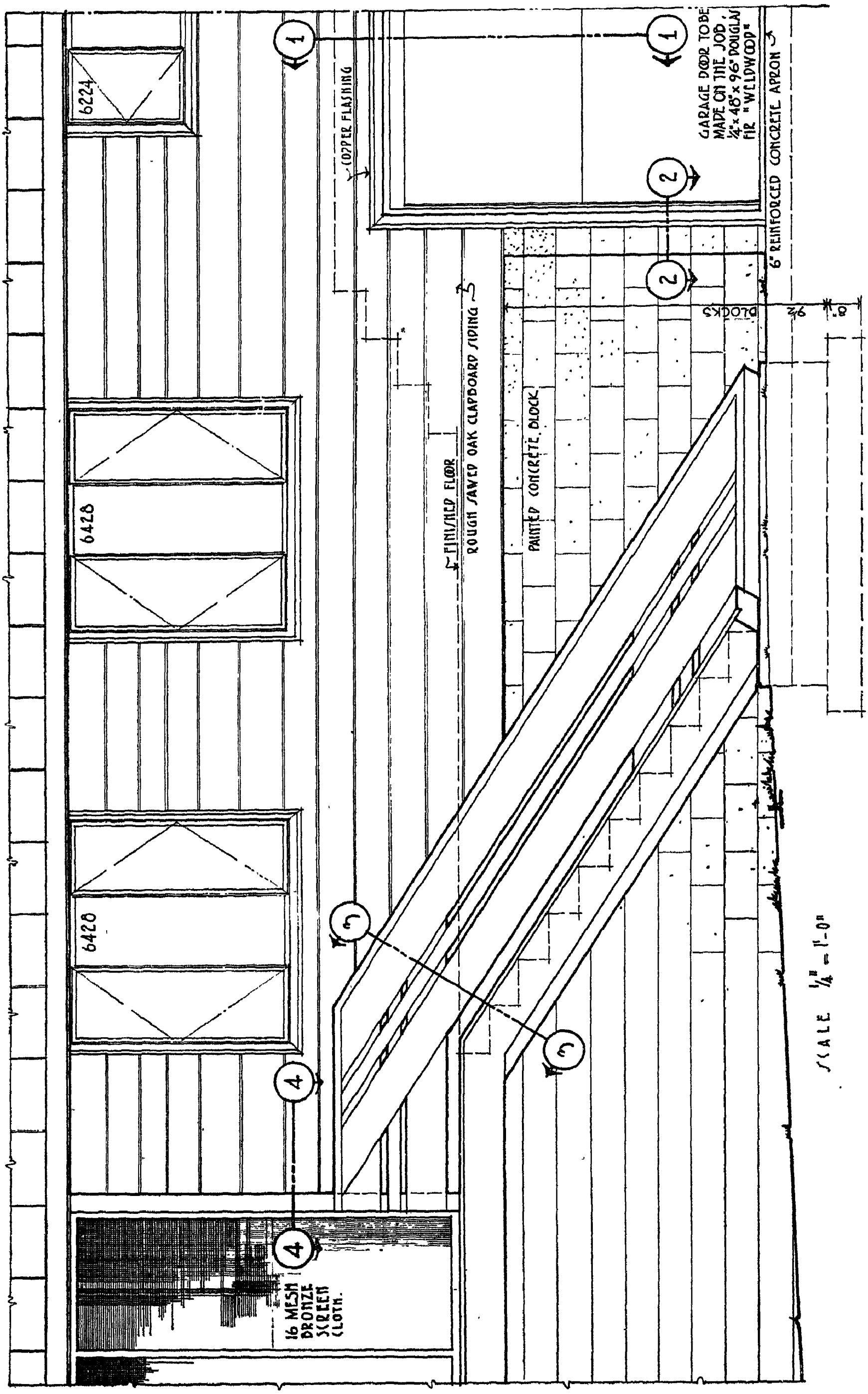


FIG. 928.—Detail elevation.

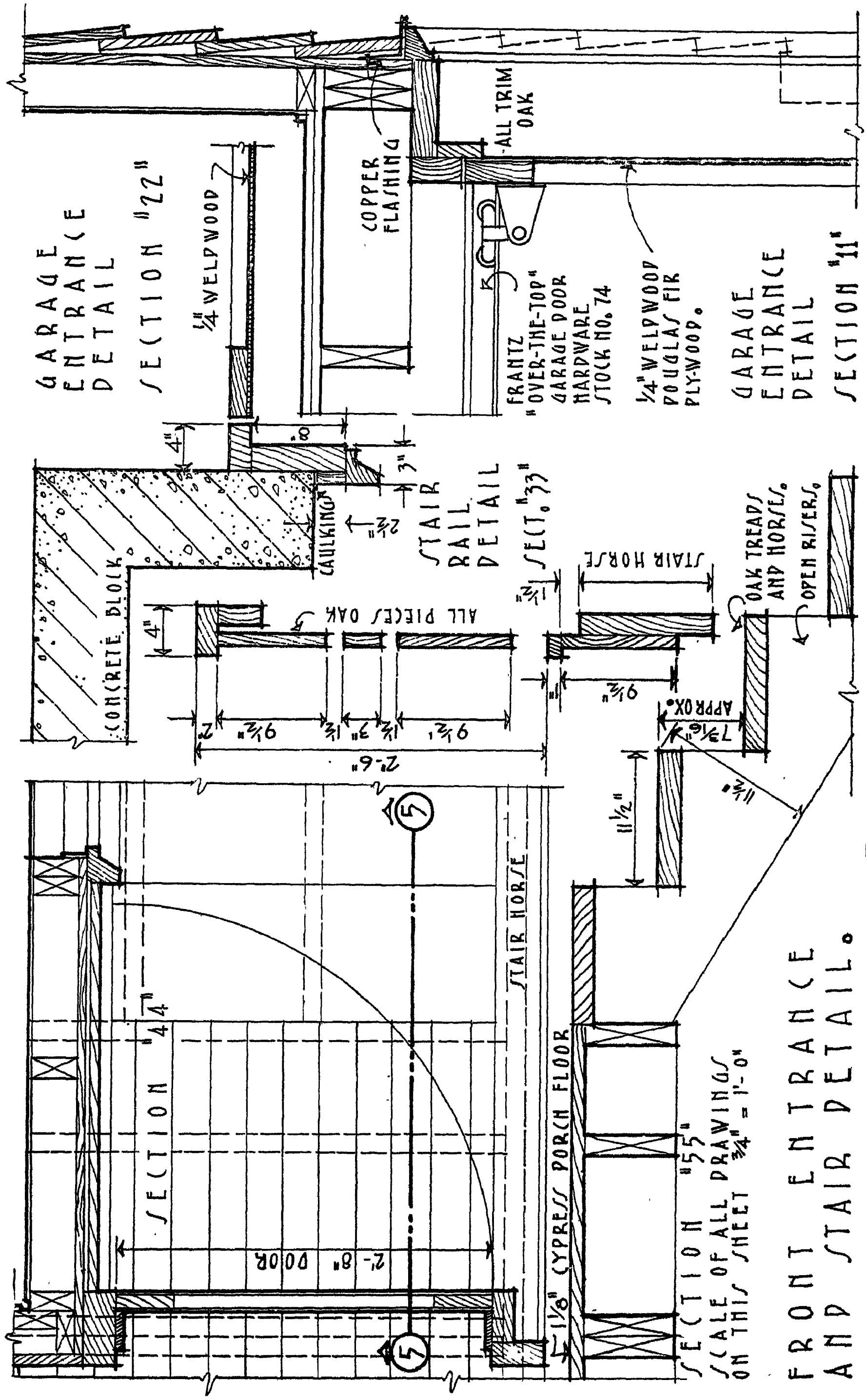


FIG. 929.—Construction details.

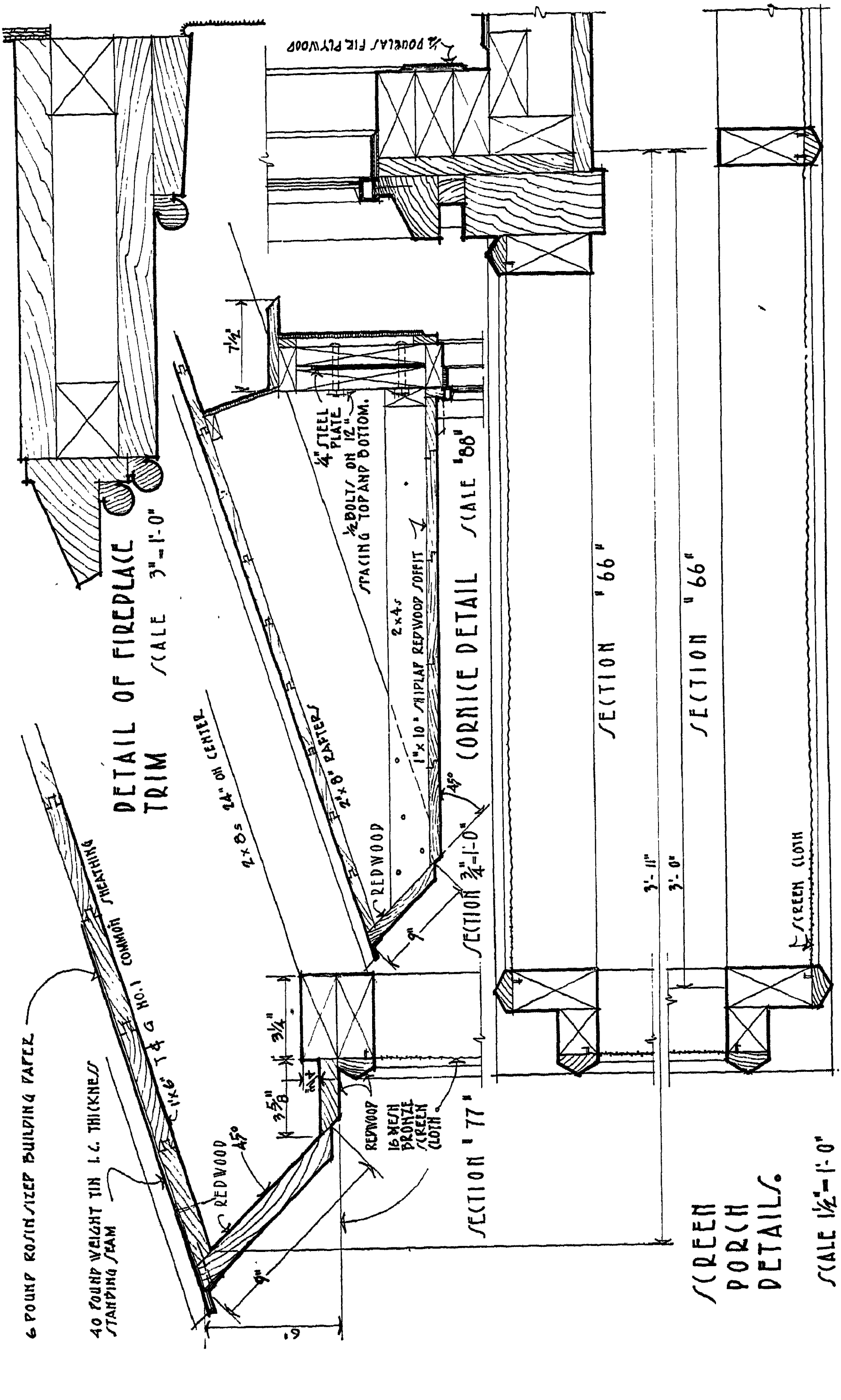


FIG. 930.—Construction details.

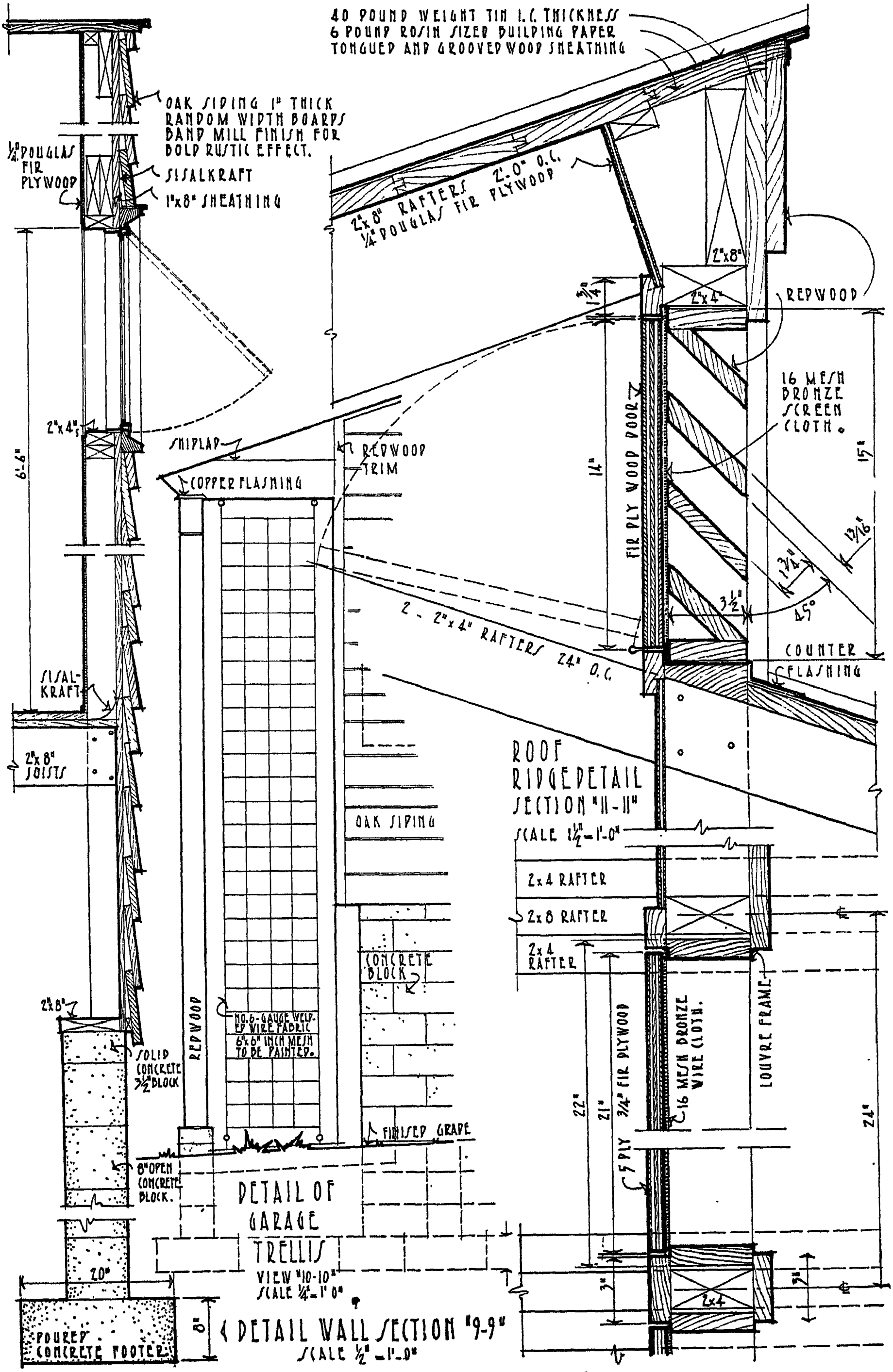


Fig. 931.—Construction details.

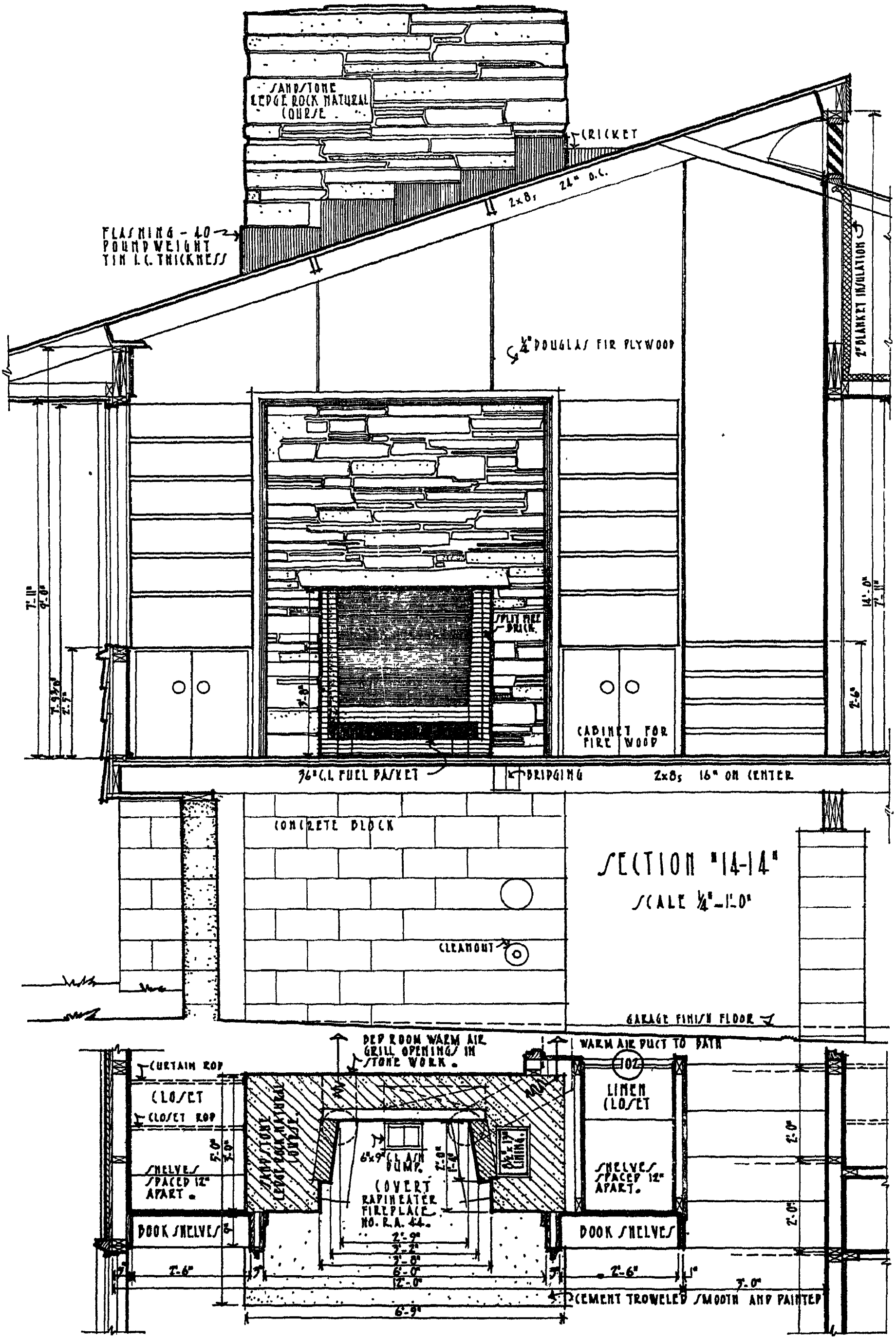


Fig. 932.—Detail cross section.

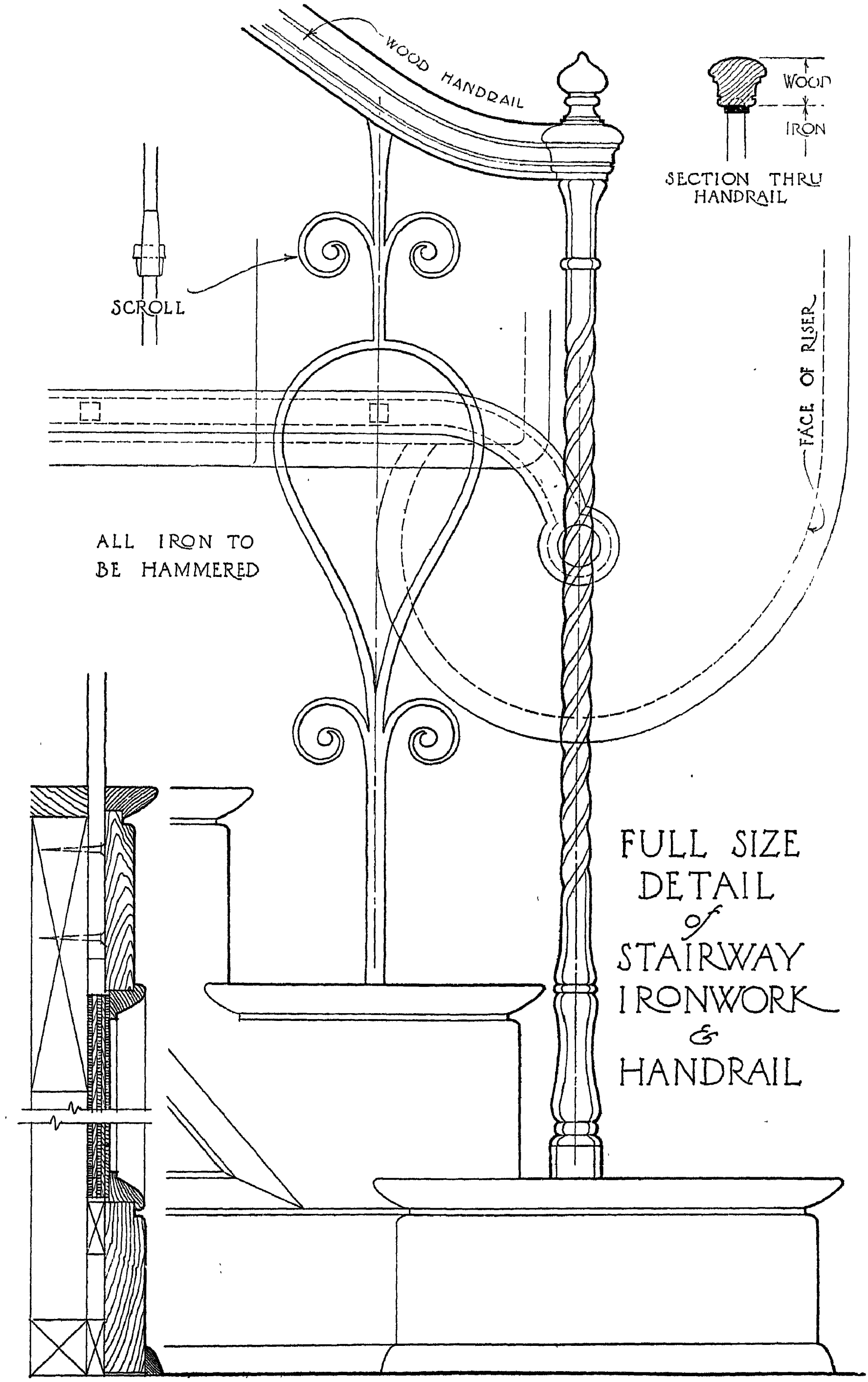


FIG. 933.—Detail showing superimposed view and profiling.

415. Details of Building Construction.—The engineer and architect are mutually dependent. In building, such questions as strength, mechanical apparatus and construction are engineering problems, while plan and exterior design are architectural problems.

In the design of a building for engineering or manufacturing purposes there are many considerations involved which the architect cannot be expected to know. The young engineer should be able to prepare prelimi-

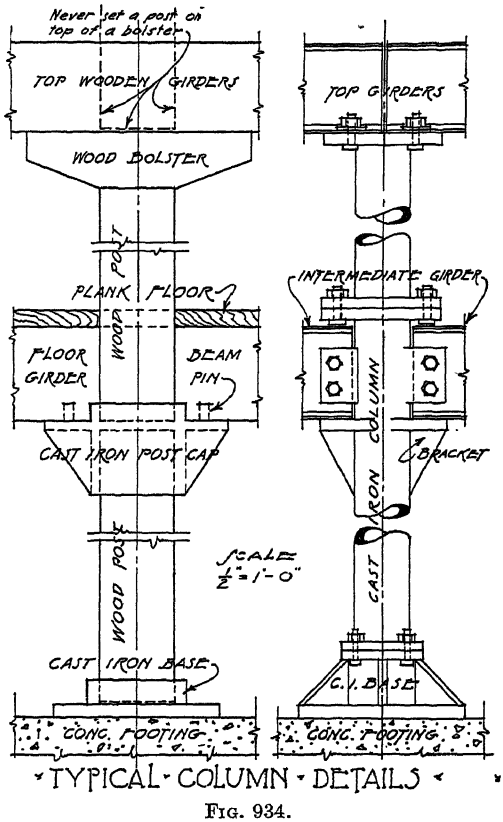


Fig. 934.

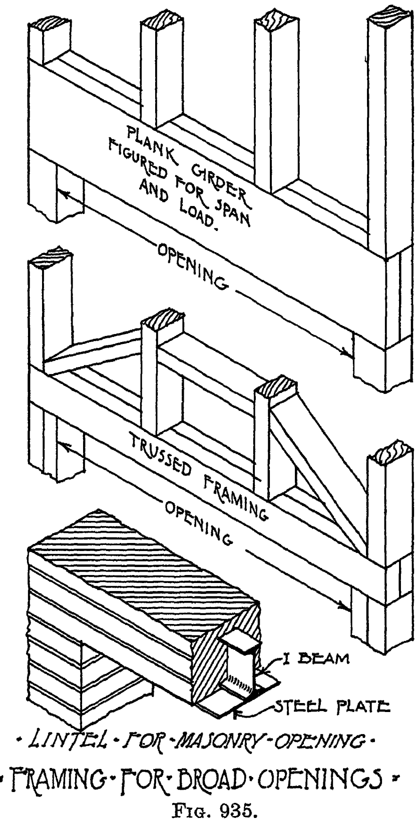


Fig. 935.

nary layouts or to make drawings for simple plant buildings. A few parts of such drawings are included here to suggest the method of representation, and the names of the different pieces are given. Column details may be represented as in Fig. 934, where the lower and upper end floor connections are illustrated. Part of the details for large openings in both brick and frame walls are given in Fig. 935.

A part of an elevation of one bent of a wooden factory building, showing the sizes and locations of the different timbers, is shown in Fig. 936. Similar drawings may be required for floor and roof framing. The extent of detail on such drawings varies, but in all cases it is necessary to have all the

information either on the drawings or in the specifications so that there will be no possibility of misunderstanding after the work is started.

416. Special Features.—In modern building construction, many parts are used which are manufactured by firms specializing in one particular item.

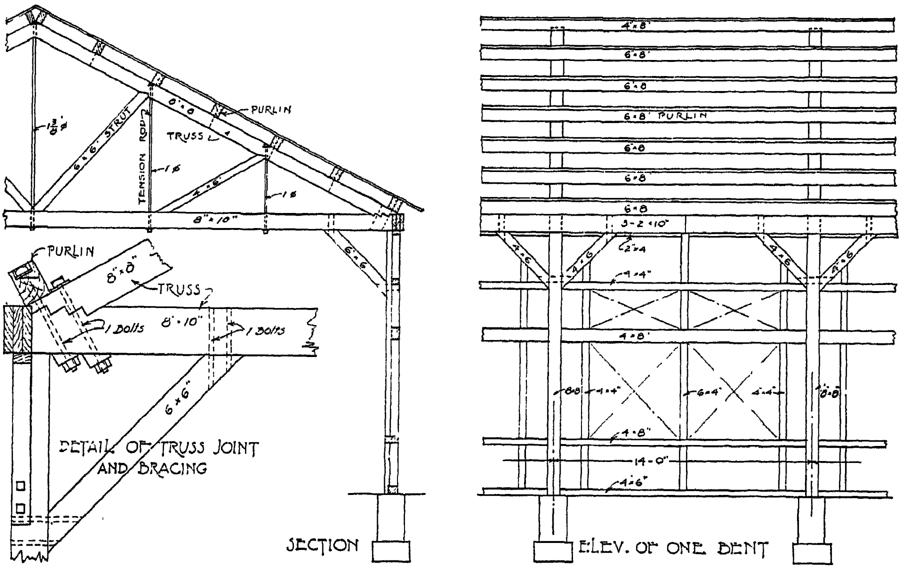


FIG. 936.—One bent, single-story shop building.

As an example, steel sash details vary with different makes. The architect gets full-size details from the makers and draws his building to conform. Similarly, other items such as ventilating fans, stock stairways, fire doors

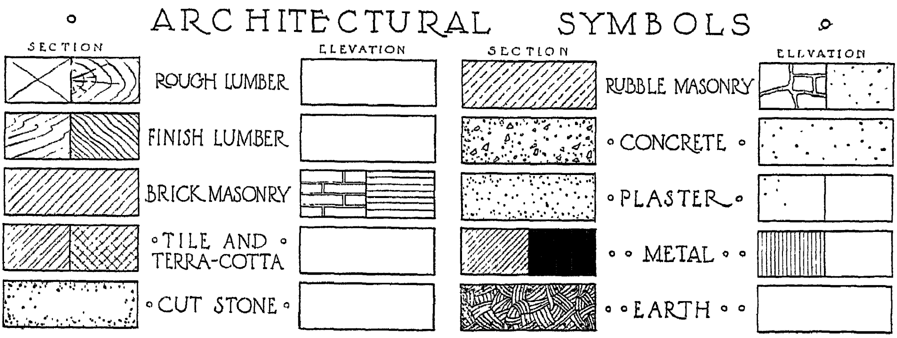


FIG. 937.—Symbols for materials.

and many other special features are always worked out from drawings furnished by the manufacturers of the equipment.

417. Symbols.—As heretofore stated, plans are largely made up of symbols. Walls are shown by double lines giving their thickness. Symbols for walls in plan and elevation are shown in Fig. 937. The conventional

method of representing windows and their derivation from the actual sections are shown in Fig. 938. The American Standard symbols for wiring plans, toilets, sinks, floor drains, etc., may be found in the Appendix.

418. Dimensioning.—The correct dimensioning of an architectural drawing requires first of all a knowledge of the methods of building construction. The dimensions should be placed so as to be most convenient for the workman, should be given to and from accessible points and should be chosen so that commercial variation in the sizes of materials will not affect the general dimensions. The principles of dimensioning found in Chap. XI are in

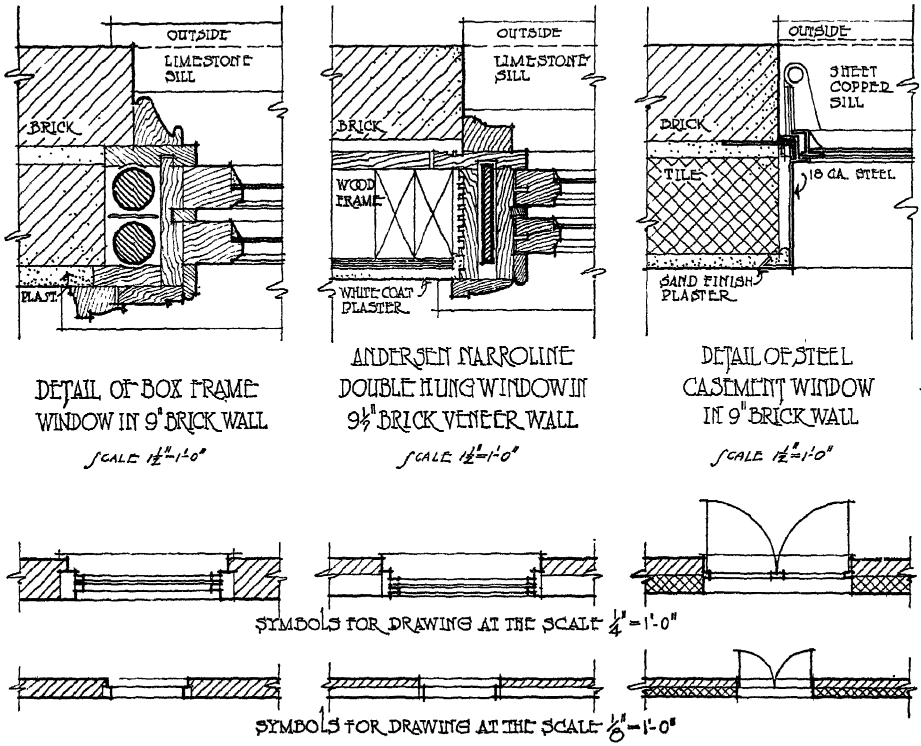


FIG. 938.—Window details and symbols.

general applicable to architectural drawing. A study of the dimensioning on the drawings in this chapter will be of much value. It will be noted that dimensions are kept outside the plans; that they are given to the outside face of masonry walls; to the center lines of door and window openings, frame partitions, beams and columns; and to the outside of studs in outside frame walls; and that vertical dimensions and glass sizes are given on elevations.

419. Notes and Specifications.—The statement that the specifications should contain the notes of explanation does not imply that no notes are to be placed on the drawings. On the contrary, there should be on architectural drawings clear, explicit notes in regard to material, construction and

finish even though repeated more fully in the specifications. The builders are apt to overlook a point mentioned only in the specifications but as they are using the drawings constantly will be sure to see a reference or note on the drawing of the part in question. Recent practice has introduced, as an item on the drawings, the "schedule," a systematic method of presenting such notes. This gives in tabular form detailed information taken from the specifications, thus making this required information easily accessible to the craftsmen. Of particular value is the *finish schedule* placed on a plan drawing and giving specifications for all rooms shown on that plan. An example is shown in Fig. 939. A door schedule, or door list, the forerunner of other schedules, is on Figs. 921 and 922.

420. Checking.—Architectural drawings require careful checking. As the draftsman develops the drawings he checks back and forth continually.

FINISH SCHEDULE • FIRST FLOOR ROOMS								
ROOM NO.	ROOM NAME	FLOOR	BASE	WALLS & CEILING	WAINSCOT	TRIM	CORNICE	REMARKS
101	HALL	YEL PINE	BIRCH	PLASTER	——	BIRCH	PICT MLD	OAK STAIR TREADS & PLATFORM
102	LIVING RM	"	"	"	——	"	"	SEE DETAILS
103	DINING RM.	"	"	"	——	"	"	" "
104	LAVATORY	TILE	4" TILE	"	KEENE'S CEM	POPLAR	——	OAK STEPS-BIRCH WDW STOOLS
105	KITCHEN	YEL PINE	POPLAR	"		"	——	SEE DET'LS- " " "
106	STAIR	YP TREADS	Y P	"		Y P	——	FINISH TO BOTTOM 1st FLOOR JOISTS
NOTE - FINISH CLOSETS SAME AS ROOMS FROM WHICH THEY OPEN • • • • •								

FIG. 939.—Finish schedule.

Before going to the tracer the design of all structural parts should be checked for strength and fitness, and the drawings should be checked for accuracy of draftsmanship and to see that all special requirements of the client are embodied (these should be on record in writing).

Tracings should be checked by a responsible checker, who should mark all dimensions with a check mark in soft black or in blue pencil and either check mistakes with red pencil or correct them. All checking should be done in a definite order, following each item through separately and systematically. This order will be dictated by the checker's preference or by conditions of the problem. The following is suggested as a guide:

1. Check main over-all dimensions on the plans, seeing that all plans agree.
2. Check location dimensions on plans, seeing that openings line up vertically, and that plan axes (center lines) "carry through" with openings designed to be on axes.
3. See that dimensions of construction and finish on details correspond to those on plans and fit into adjacent features. Large-scale details made as the work progresses must be checked to measurements made at the building.
4. Check stair dimensions carefully, both as to rise and run and to headroom at close places.
5. Check all vertical dimensions on elevations and vertical sections.
6. Check glass sizes of windows and glazed doors.
7. Check all door sizes and see that doors are completely described by note, drawing or specification.
8. Check design, length and notation of steel lintels over windows and doors as shown on elevations, and compare with large-scale details.

9. Check sizes and locations of all ducts and flues.
10. Check location and kind of wiring outlets.
11. Check for clearances for all mechanical equipment, including heating, ventilating, plumbing and wiring.
12. See that all notes are complete and accurate.
13. Check the titles for correctness of statement and spelling.
14. Check specifications for typographical errors.
15. Check the specifications with the drawings. Although the specifications ordinarily take precedence over the drawings, there should be no discrepancy.
16. Check specifications to see that all fixtures and apparatus for plumbing, heating and lighting systems are specified.
17. Check for conformity with building codes and laws.

421. Lettering.—There are two distinct divisions in the use of lettering by the architect, the first, *office lettering*, including all the titles and notes put

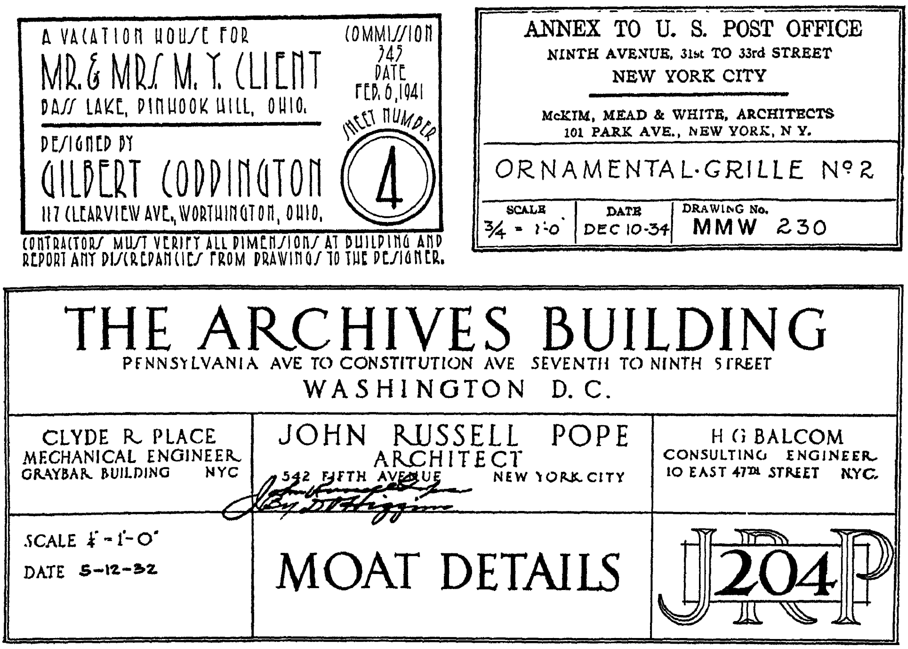


Fig. 940.—Working drawing titles.

on the drawings for information, and the second, *design lettering*, covering drawings of letters to be executed in stone or bronze or other material in connection with design.

The Old Roman is the architect's one general-purpose letter, which serves him, with few exceptions, for all his work in both divisions. It is a difficult letter to execute properly, and the draftsman should make himself thoroughly familiar with its construction, character and beauty before attempting to design inscriptions for permanent structures or even titles.

422. Titles.—Titles on display drawings are usually carefully made in Old Roman in either outline or solid. One alphabet is given in Fig. 118. On

working drawings a rapid single stroke based on Old Roman, such as Fig. 120, is used.

An architectural title should contain part or all of the following items:

1. Name and location of structure.
2. Kind of view, as roof plan (sometimes put elsewhere on sheet).
3. Name and address of client.
4. Date.
5. Scale.
6. Name and address of architect.
7. Number (in set).
8. Key to materials.
9. Office record.
10. For public buildings, space for signed approval of authority.

Three examples of working-drawing titles are given in Fig. 940, the first a drawn title, the second a stamp title, such as is made for a large project where hundreds of drawings are required, and the third a finished title in roman letters.

PROBLEMS

423. The following problems are suggested for practice in architectural drawing. The student should have ready access to information on present-day building materials. Use ¼″ scale for plans and elevations, ¾″ for wall sections and ½″ for details.

1. Draw the south elevation of the house shown in Figs. 920 to 924, getting the information from these drawings.

2. Draw the east elevation of foregoing house.

3. Make a complete set of working drawings for a vacation house, developing the preliminary drawings shown in Figs. 926 and 927. Figures 928 to 932 are given for the detail information concerning materials and construction. At this stage in the progress of a job through an architect's office the chief draftsman will prepare a schedule of the principal drawings and details to be shown. The following is a suggested outline for the draftsman to follow:

Sheet No. 1. PLOT PLAN. Scale ⅛″ = 1′-0″. Show septic-tank location and a detail of filter bed.

Sheet No. 2. SECOND FLOOR PLAN. Scale ¼″ = 1′-0″. Show first floor framing plan.

Sheet No. 3. FIRST FLOOR PLAN. Scale ¼″ = 1′-0″.

Sheet No. 4. CROSS SECTION. Scale ¼″ = 1′-0″. See Fig. 932 for drafting technique. Show a detail of fireplace, bookcases, ridge louvers and cornice.

Sheet No. 5. NORTH ELEVATION. Scale ¼″ = 1′-0″. See Fig. 928 for drafting technique. Show construction detail for stairway and garage doorway.

Sheet No. 6. EAST ELEVATION. Scale ¼″ = 1′-0″. Show construction detail for porch-screen frames and cornices.

Sheet No. 7. SOUTH ELEVATION. Scale ¼″ = 1′-0″. Show construction detail for garage window.

Sheet No. 8. WEST ELEVATION. Scale ¼″ = 1′-0″. Show west end wall section and trellis detail.

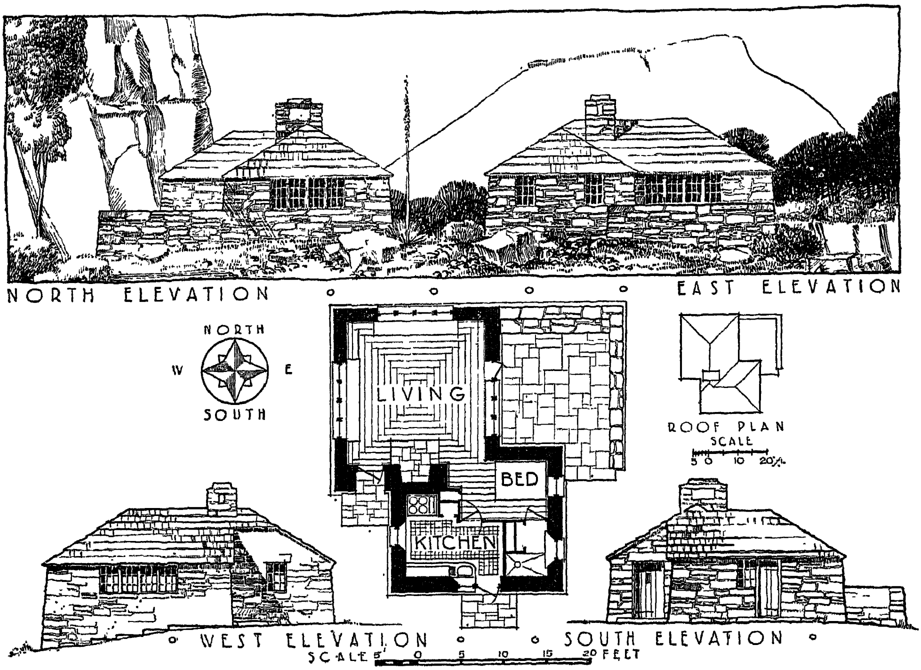


FIG. 941.—A week-end cottage.

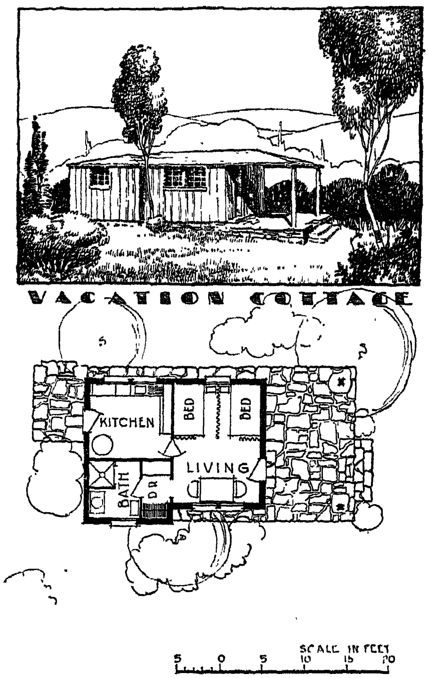


FIG. 942.—A vacation cottage.

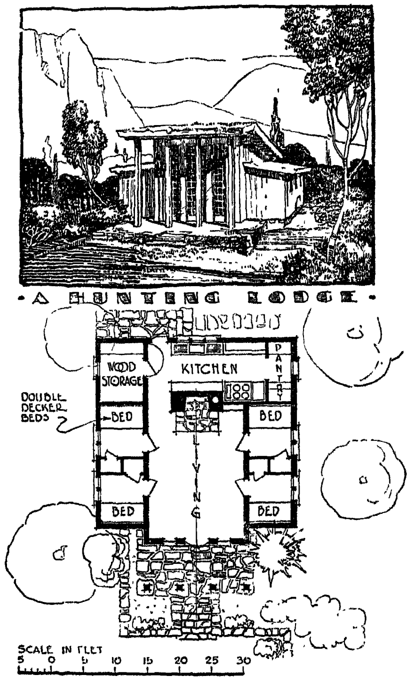


FIG. 943.—A hunting lodge.

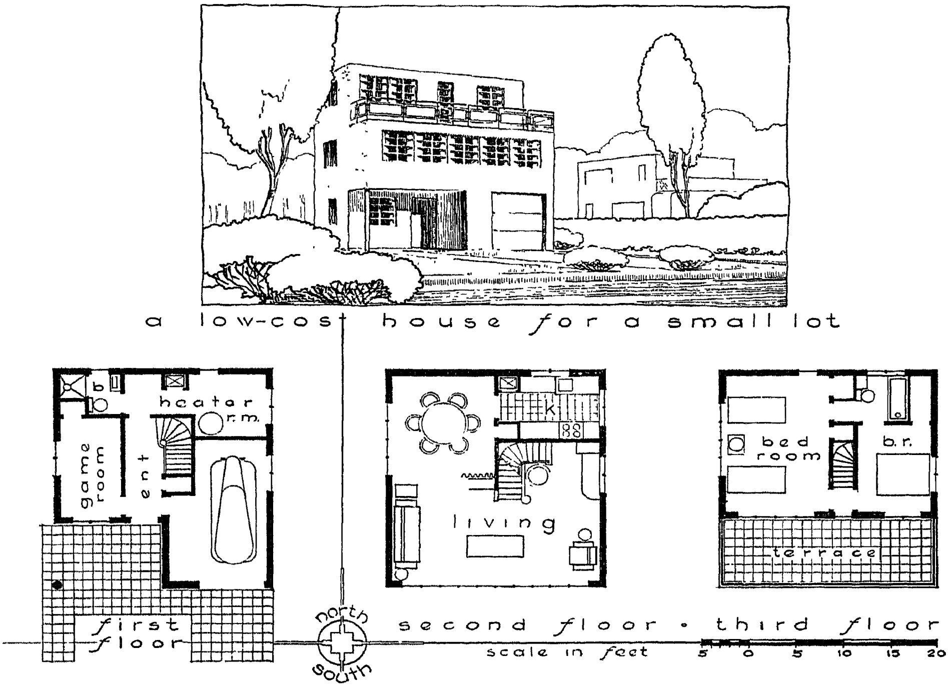


FIG. 944.—A small house.

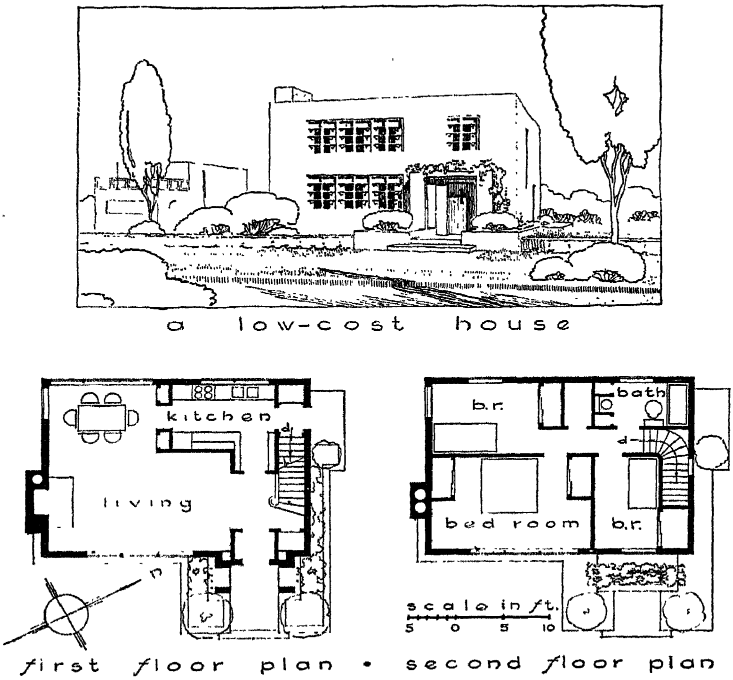


FIG. 945.—A modern house.

4. Fig. 941. Make floor plan, elevations and roof framing plan for week-end cottage. In its construction it is suggested that the walls be solid masonry of rough-faced field stone, that roof timbers be of old barn timbers or beams hewed to fit from trees on the site, that the floor be of flagstone with cement joints, that the roof be of heavy slate or large shakes, and that the woodwork be of barn boards or unfinished lumber, stained.

5. Fig. 942. Make set of working drawings for vacation cottage. Foundation of field stone.

6. Fig. 943. Make working drawings for hunting lodge. Field-stone foundation, hewed-timber construction and sod roof.

7. Fig. 944. Make working drawings for house shown. Concrete foundation. Walls of stucco, sheetrock or metal, backed with insulation. Fireproof construction and steel sash preferred.

8. Fig. 945. Make working drawings for house shown, with choice of building materials.

9. Figs. 918, 919. Make working drawings for house shown. First floor, limestone; second floor, brick to match. First floor lintels, reinforced concrete. Fireproof floor, partitions and roof.

CHAPTER XXV

THE ELEMENTS OF STRUCTURAL DRAWING

424. Structural drawings differ from other drawings only in certain details and practices which have developed as peculiar to the materials worked with and the method of their fabrication. The differences are so well established that it is essential for any engineer to know something of the methods of representation in use in structural work.

Steel structures are made up of "rolled shapes" put together permanently by riveting or welding. The function of a structural drawing is to show the shapes and sizes used and the details of fastening. Sections of the usual structural shapes are shown in Fig. 946.

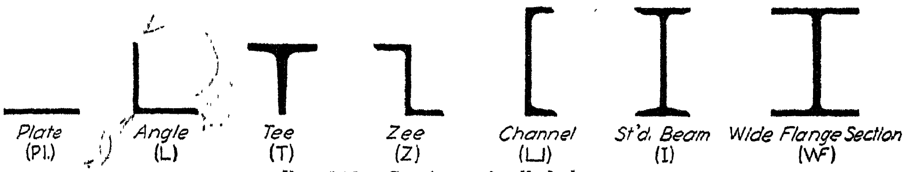


FIG. 946.—Sections of rolled shapes.

The dimensions of the various sizes of standard steel shapes, together with much other information with which the structural draftsman must be familiar, are given in the various structural-steel handbooks. For wooden structures, where the parts are not so completely standardized, complete details and dimensions of every part are desirable.

A glossary of terms used in structural drawing is given in the Appendix.

425. Classification.—Professor Ketchum[1] has classified and described the drawings for structures as follows:

(1) **General Plan.**—This will include a profile of the ground; location of the structure; elevations of ruling points in the structure; clearances; grades; direction of flow, high water, and low water (for a bridge); and all other data necessary for designing the substructure and superstructure.

(2) **Stress Diagram.**—This will give the main dimensions of the structure, the loading, stresses in all members for the dead loads, live loads, wind loads, etc., itemized separately; the total maximum stresses and minimum stresses; sizes of members; typical sections of all built members showing arrangement of material; and all information necessary for detailing the various parts of the structure.

(3) **Shop Drawings.**—Shop detail drawings should be made of all steel- and ironwork, and detail drawings should be made of all timber, masonry and concrete work.

[1] *Structural Engineers' Handbook* by Milo S. Ketchum.

(4) **Foundation or Masonry Plan.**—The foundation or masonry plan should contain detail drawings of all foundations, walls, piers, etc., that support the structure. The plans should show the loads on the foundations, the depth of footings, the spacing of piles where used, the proportions for the concrete, the quality of masonry and mortar, the allowable bearing on the soil, and all data necessary for accurately locating and constructing the foundations.

(5) **Erection Diagram.**—The erection diagram should show the relative location of every part of the structure, shipping marks for the various members, all main dimensions, number of pieces in a member, packing of pins, size and grip of pins, and any special feature or information that may assist the erector in the field. The approximate weight of heavy pieces will materially assist the erector in designing his falsework and derricks.

(6) **Falsework Plans.**—For ordinary structures it is not common to prepare falsework plans in the office, this important detail being left to the erector in the field. For difficult or important work, erection plans should be worked out in the office and should show in detail all members and connections of the falsework and also give instructions for the successive steps in carrying out the work. Falsework plans are especially important for concrete and masonry arches and other concrete structures, and for forms for all walls, piers, etc. Detail plans of travelers, derricks, etc., should also be furnished the erector.

(7) **Bills of Material.**—Complete bills of material showing the different parts of structure with its mark and the shipping weight should be prepared. This is necessary to permit checking of shipping weights and shipment and arrival of materials.

(8) **Rivet List.**—The rivet list should show the dimensions and number of all field rivets, field bolts, spikes, etc., used in the erection of the structure.

(9) **List of Drawings.**—A list should be made showing the contents of all drawings belonging to the structure.

426. General Drawings.—The general drawings correspond in many respects to the design drawings and assembly drawings of the mechanical engineer and include the general plan, the stress diagram and the erection diagram. In some cases the design drawing is worked out completely by the engineer, who gives the sizes and weights of members and the number and spacing of all rivets, but in most cases the general dimensions, positions and sizes of the members and the number of rivets are shown, leaving the details to be worked out in the shop or to be given on separate complete detail shop drawings.

In order to show the details clearly the structural draftsman often uses two scales in the same view, one for the center lines or skeleton of the structure, showing the shape, and a larger one for the parts composing it. The scale used for the skeleton is determined by the size of the structure as compared with the sheet; ¼″, ⅜″ and ½″ to 1′-0″ are commonly used. Shop details are made ¾″, 1″ or 1½″, and, for small details, 3″ to the foot. Figure 947 is a typical drawing of a small roof truss, giving complete details. Such drawings are made about the working lines used in calculating the stresses and sizes of the members. These lines are usually the gravity lines

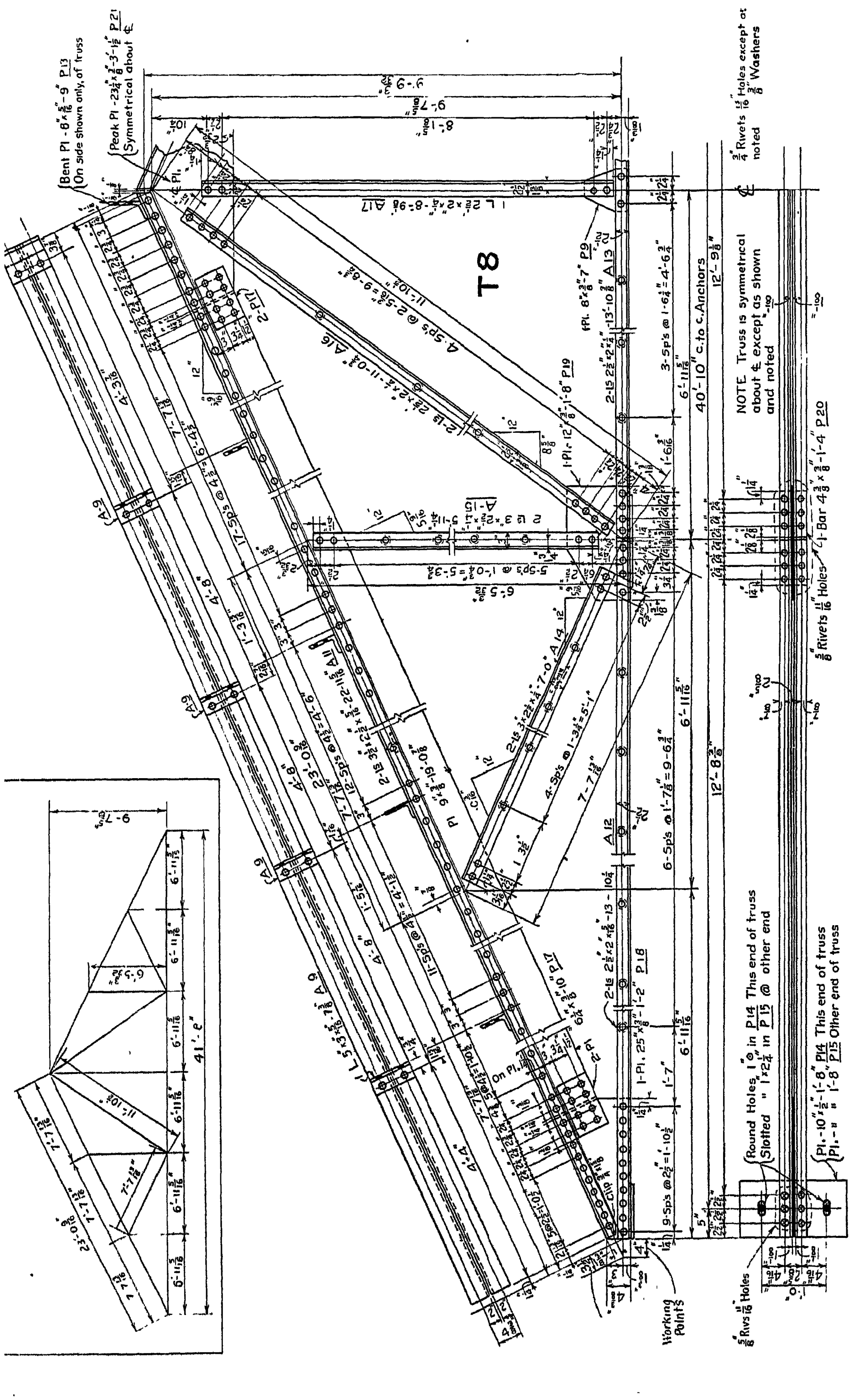


FIG. 947.—Structural working drawing; roof truss.

of the members and form the skeleton, as illustrated separately to small scale in the box on the figure. The intersections of these lines are called "*working points*" and are the points from which all distances are figured. The length of each working line is computed accurately, and from it the intermediate dimensions are obtained.

The erection diagram is often put on the same sheet, as with the drawing of the truss.

When one-half of a truss only is shown, it is always the left end, looking toward the side on which the principal connections are made.

In building construction a beam schedule and a column schedule, giving the detailed information concerning these members, should be added on the drawings.

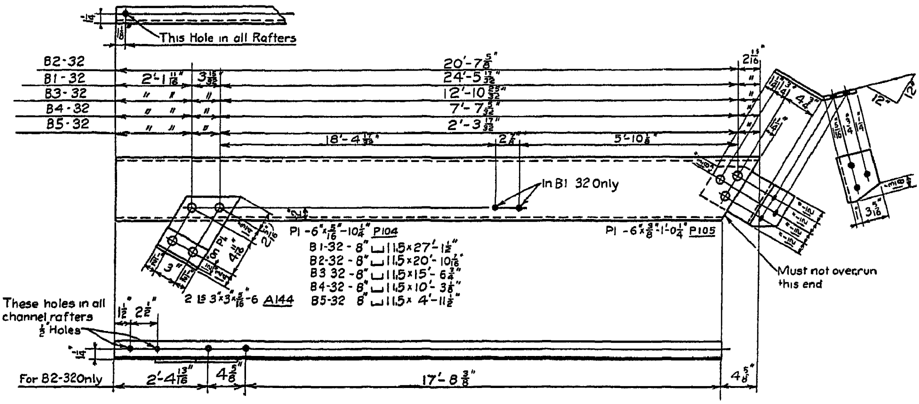


FIG. 948.—Beam detail.

427. Detail Drawings.—Separate drawings made to a sufficiently large scale to carry complete information are called "shop detail drawings." All parts are shown to scale, and it should be noted particularly that rivets and rivetheads are drawn accurately to scale. When possible, the drawings of all members are shown in the same relative position which they will occupy in the completed structure: vertical, horizontal or inclined. Long vertical or inclined members may be drawn in a horizontal position, a vertical member always having its lower end at the left, and an inclined member drawn in the direction it would fall. Except in plain building work, a diagram to small scale showing by a heavy line the relative position of the member in the structure should be drawn on every detail sheet.

Figure 948 is a beam detail, giving all the information for five different beams in one drawing and illustrating the method of representing a bent plate. It is obvious that in such a drawing the lengths are not to scale.

As the various members are detailed they are given a mark, such as B1-32 (B for beam; 1, the shop number; and 32, the sheet number of the detail drawing), for identification in assembling.

428. Structural Drawing Practice.—All drawings in an office should be made to standard sizes. The American Standard 17″ × 22″, 22″ × 34″ and 34″ × 44″ sheets are common.

Half-inch borders are generally used. Inked outlines should be of sufficient weight to make the main material stand out distinctly, while dimension lines and gage lines are made in very fine full lines in black. Some prefer red ink for dimension and gage lines. This makes the tracing somewhat easier to read, but the prints are not so satisfactory, and it is difficult to get a permanent red ink. When new work is to be attached to old, the old is often drawn in red. Tracing paper or pencil cloth is extensively used for shop details, and occasionally sketches substitute for an instrument drawing. Assemblies in pencil, on vellum, may be used when the permanence of ink is not an essential feature.

Dimensions are always placed *over* the dimension line instead of in a space left in the line. Lengths of 10″ and over are given in feet and inches, thus, 0′-10″, 1′-2½″. Care should be taken that dimensions are given to commercial sizes of materials. Sizes of members are specified by figures parallel to them as 2L-2½ × 2 × ¼ × 7′-3″, which means two angles having unequal legs of 2½″ and 2″, ¼″ thick and 7′-3″ long. Angular dimensions are indicated by tangents on a 12″ base line, shown on a small triangle adjacent to the inclined member.

The dimensions necessary for the sections of Fig. 946 with the abbreviations for sections to be used on drawings, as adopted by the American Institute of Steel Construction, are as follows:

Plates.—Width × thickness × length (Pl 18 × ½ × 10′-0″).

Equal-leg Angles.—Size of legs × thickness × length (L3 × 3 × ¼ × 10′-0″).

Unequal-leg Angles.—Size of long leg × short leg × thickness × length (L7 × 4 × ½ × 10′-0″).

Tees.—Height × width × weight per foot × length (T3 × 3 × 6.7 × 10′-0″).

Zees.—Height × thickness × weight per foot × length (Z6 × 3½ × 15.7 × 10′-0″).

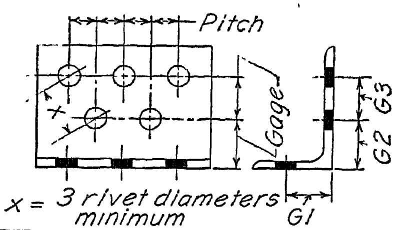
Standard Channels.—Height × weight per foot × length (9⊔ 13.4 × 10′-0″).

Standard I Beams.—Height × weight per foot × length (15 I 42.9 × 10′-0″).

Wide-flange Sections.—Height × weight per foot × length (24WF 74× 10′-0″).

Checking is usually indicated by a dot in red ink or pencil placed under the dimension. Elevations, sections and other views are placed in relation to each other by the rules of third-angle projection, except that when a view is given under a front view, as in Figs. 947 and 948, it is made as a section taken above the lower flange, looking down, instead of as a regular bottom view looking up. Large sections of materials are shown with uniform cross-hatching. Small-scale sections are blacked-in solid, with white spaces left between adjacent pieces.

Rivets are spaced along "gage lines," measured from the backs of angles and channels and from center to center on I beams. The distance between



LEG	G1	G2	G3	MAX RIVET
8	4½	3	3	1 1/8
7	4	2½	3	1 1/8
6	3½	2½	2¼	1
5	3	2	1¾	1
4	2½			7/8
3½	2			7/8
3	1¾			7/8
2½	1 3/8			3/4
2	1 1/8			5/8
1¾	1			1/2
1½	7/8			3/8
1 3/8	7/8			3/8
1¼	3/4			3/8
1	5/8			1/4
3/4	1/2			1/4

FIG. 949.—Gage and pitch.

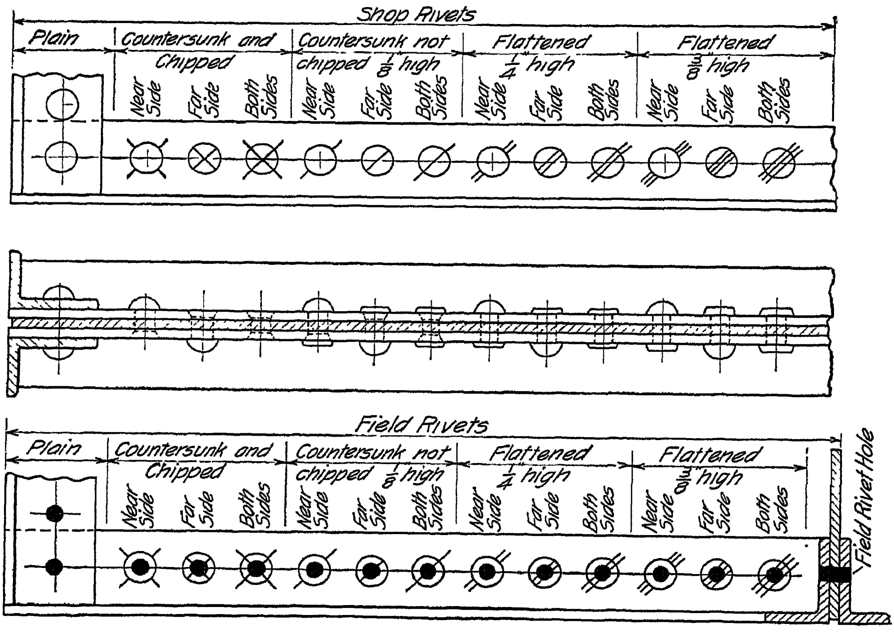


FIG. 950.—American Standard rivet symbols.

rivets measured along the gage line is called the "pitch." The gages and pitch for various angles are shown in Fig. 949.

The size of most structures prevents their being completed in the shop, so they are "fabricated" as large as transportation facilities allow, and the necessary connections made where the structure is erected. The holes for these "field rivets" are always indicated in solid black to scale on the drawing, while shop rivets are indicated by circles of the diameter of the rivet-head. A bill of field rivets is always furnished. In drawing rivets, the drop pen, Fig. 1032, is a favorite instrument.

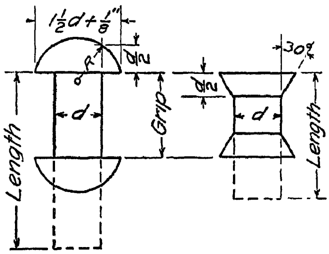
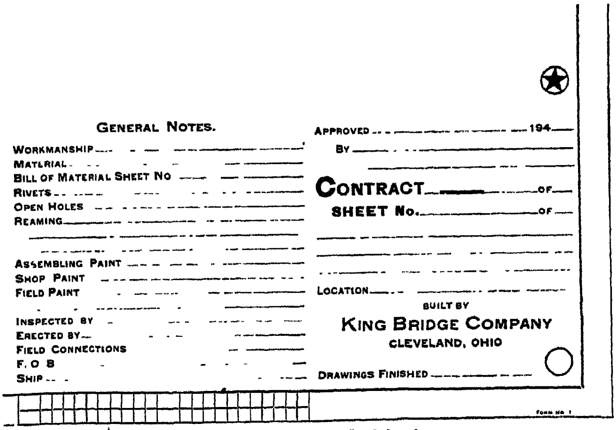


Fig. 951.—Structural rivets.

A general note is usually added to all detail drawings, giving rivet sizes, size of open holes and edge distance (unless noted) and painting instructions, as, "Paint one coat of red lead (or black graphite) in shop. Paint all parts in contact before assembly."

Figure 950 shows the American Standard symbols for riveting, formerly called the "Osborn symbols," which are so universally used that no key on the drawing is necessary. Figure 951 shows rivets to larger scale.

There is a growing use of arc welding instead of riveting for fabricating structural work. See Chap. XV.


GENERAL NOTES.

WORKMANSHIP
MATERIAL
BILL OF MATERIAL SHEET NO
RIVETS
OPEN HOLES
REAMING
ASSEMBLING PAINT
SHOP PAINT
FIELD PAINT
INSPECTED BY
ERECTED BY
FIELD CONNECTIONS
F. O. B.
SHIP

APPROVED 194
BY
CONTRACT OF
SHEET No. OF
LOCATION
BUILT BY
KING BRIDGE COMPANY
CLEVELAND, OHIO
DRAWINGS FINISHED

Fig. 952.—A printed title form.

Bent plates should be developed, and the "stretchout" length of bent forged bars given. The length of a bent plate may be taken as the inside length of the bend plus half the thickness of the plate for each bend.

A bill of material always accompanies a structural drawing. This may be put on the drawing, but the best practice is to attach it as a separate "bill sheet," generally on $8\frac{1}{2}'' \times 11''$ paper.

Each member of a structure is given a shipping mark, consisting of a capital letter and a number, which appears on the drawings and on the bill sheet. See Figs. 947 and 948.

Lettering is done in rapid single stroke either inclined or vertical. An example of a printed title form is given in Fig. 952.

429. Timber Structures.—The representation of timber framed structures involves no new principles but requires particular attention to details. Timber members are generally rectangular in section and are specified to nominal sizes in even inches, as 8″ × 12″. As nominal sizes are generally larger than the actual dimensions the general drawing must give center and other important distances accurately. Details drawn to larger scale give specific information as to separate parts. Sizes of wood members vary so

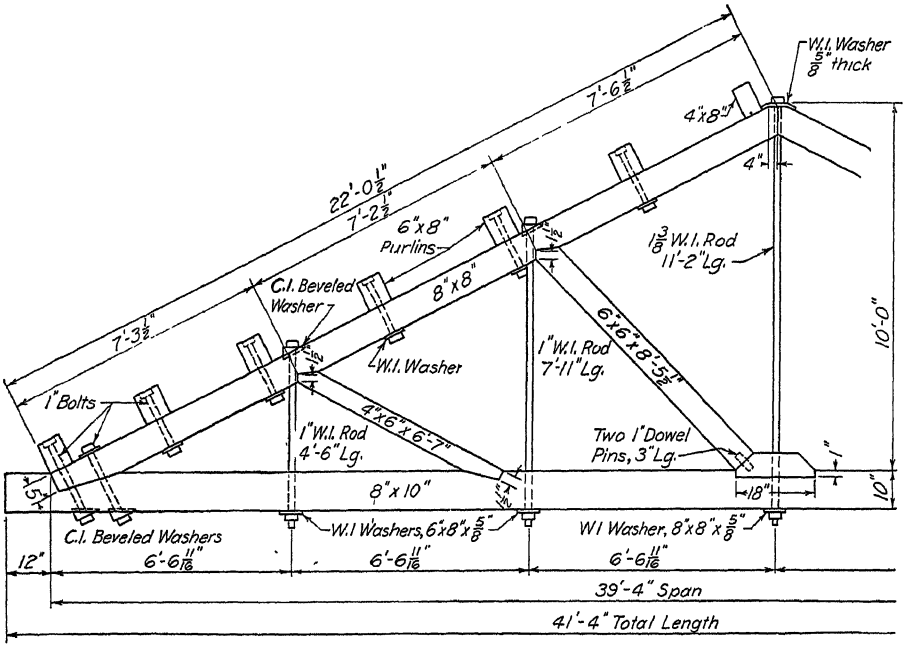


FIG. 953.—Timber truss drawing.

much that nothing should be left to "guess in" when erecting. The particulars of joints, splices, methods of fastening, etc., should be given in full.

Two scales may sometimes be used to advantage on the general drawing, as was done in Fig. 953.

Figure 954 shows the construction of a wooden trestle on piles. Timbers of the sizes shown are used for heights up to 20 feet. Complete notes are an essential part of such drawings, especially when an attempt at dimensioning the smaller details would result in confusion.

430. Timber Fastenings.—Joints in timber structures may be fastened with nails or spikes, wood screws, bolts, or modern ring-shaped or flat *connectors* in action similar to a dowel or key. Some common types are shown

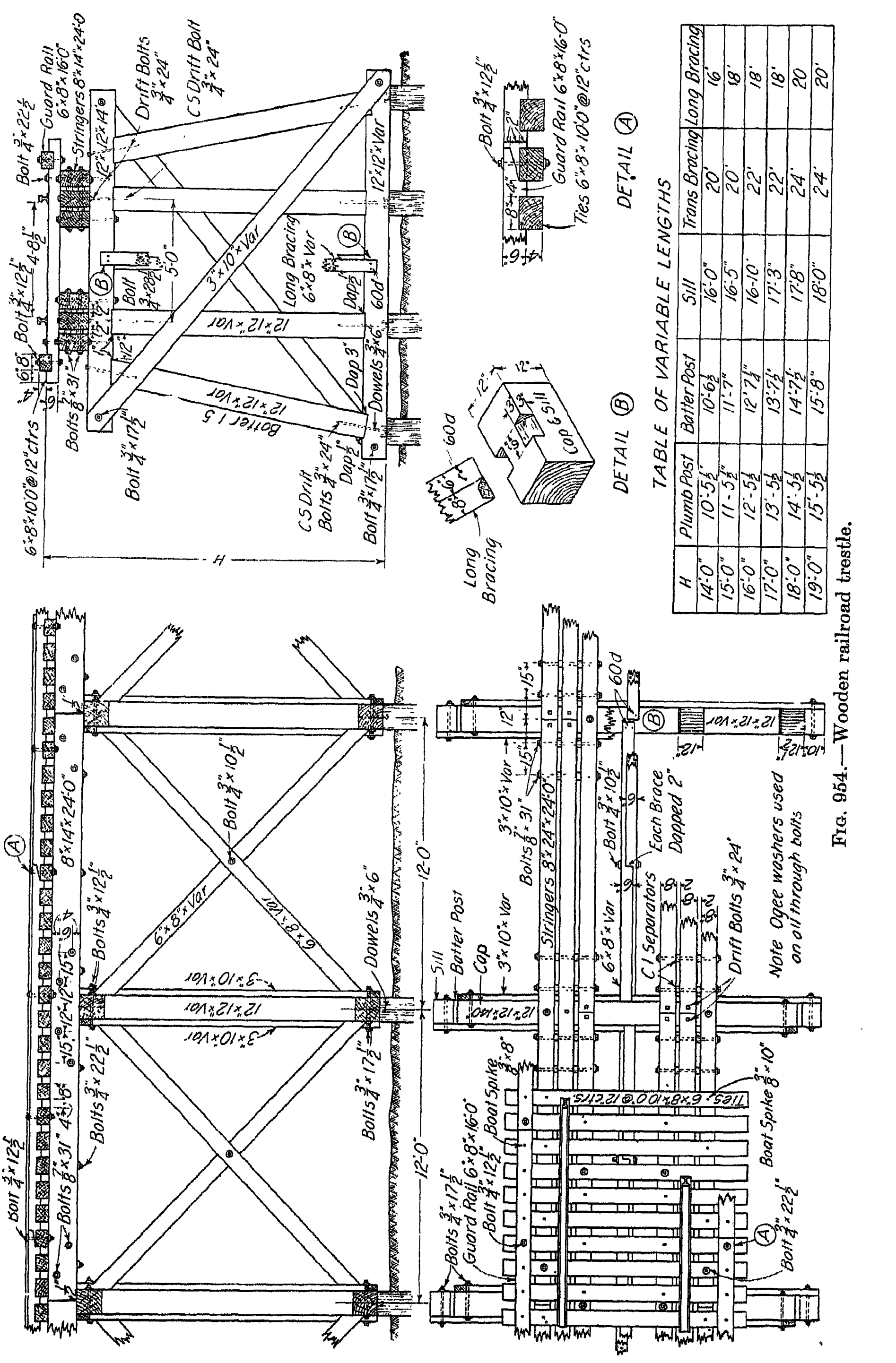


TABLE OF VARIABLE LENGTHS

H	Plumb Post	Batter Post	Sill	Trans Bracing	Long Bracing
14'0"	10'-5½"	10'-6½"	16'-0"	20'	16'
15'0"	11'-5½"	11'-7"	16'-5"	20'	18'
16'0"	12'-5½	12'-7¼"	16'-10'	22'	18'
17'0"	13'-5½	13'-7½	17'3"	22'	18'
18'0"	14'-5½	14'-7½	17'8"	24'	20
19'0"	15'-5½	15'8"	18'0"	24'	20'

FIG. 954.—Wooden railroad trestle.

in Fig. 955. *A* is a split ring, assembled in grooves in each piece and held together with a bolt, as indicated at *B*. The sharp projections on the alligator connector *C* are forced into the members by pressure. The *claw-plate*

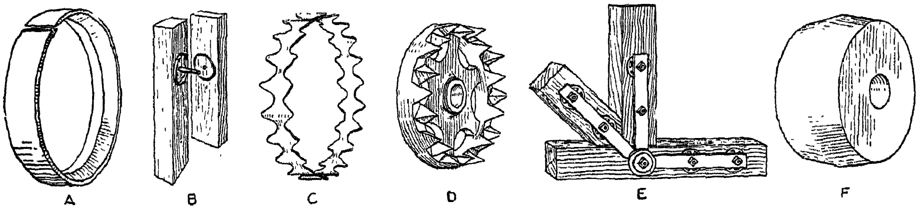


FIG. 955.—Connectors.

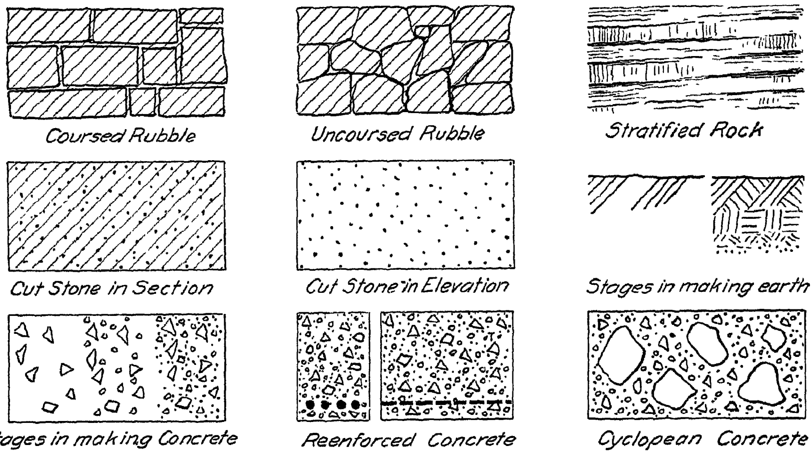


FIG. 956.—Masonry symbols.

connector *D* is used either in pairs, back to back, for timber-to-timber connections, or single for timber to metal. A typical assembly is shown at *E*. The Kubler wood dowel connector *F* fits into a bored hole in each timber face, and a bolt holds the parts together.

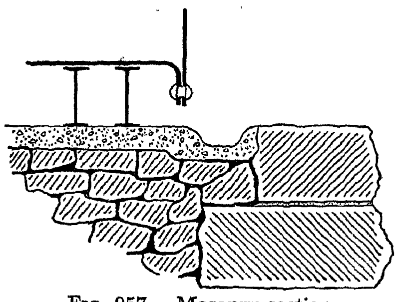


FIG. 957.—Masonry section.

The Forest Products Laboratory publication, *Wood Handbook*, gives basic information on wood as a material of construction, including the modern connectors, and is available at small cost from the Superintendent of Documents, Washington, D.C.

431. Masonry Structures.—In drawing masonry the symbols used bear some resemblance to the material represented. Figure 956 gives those in common use and shows the stages followed to secure uniformity of effect in rendering earth and concrete. An effective method of crosshatching, leaving a white margin around the edge of the stone is shown in Fig. 957. Drawings for piers, foundations for machines

and other structures are met with in all kinds of engineering work. Grade levels, floor levels and other fixed heights should be given, together with accurate location dimensions for foundation bolts. All materials should be marked plainly with name or notes. A pier is illustrated in Fig. 958.

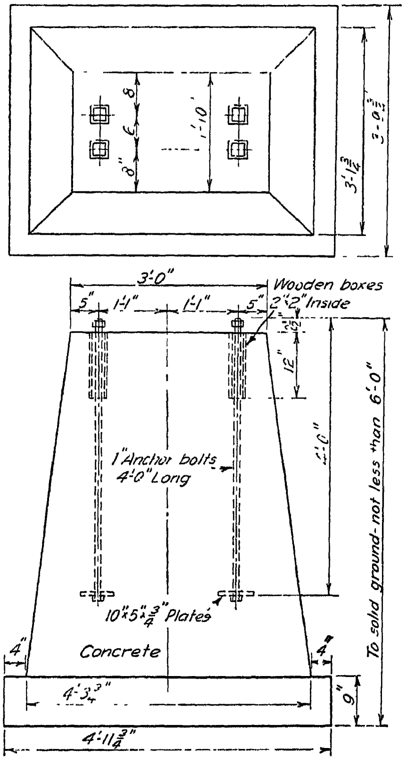


FIG. 958.—Pier drawing.

432. Reinforced concrete is an important division of masonry construction needing careful attention in representation. It is almost impossible to show definitely the shapes of reinforcing bars in concrete by the usual orthographic views, without a systematic scheme of marking. In Fig. 959 the various bars are designated by reference letters and numbers on horizontal and vertical center lines. Note the horizontal lines G and F, and the vertical lines numbered 1, 2, 3, 4, 5. The first bar in the line G is called $G1$, the second $G2$, etc., similarly for bars $F1$, $F2$. Each of the bars is marked with its same combination of letter and figure in the other views, and they are detailed in separate bending diagrams, thus completely

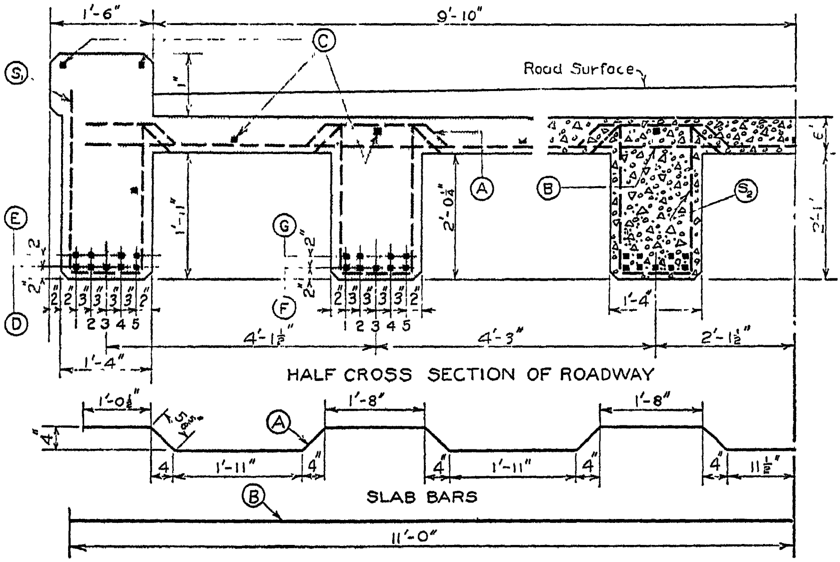


FIG. 959.—Reinforced concrete section.

defining their location and shape. Sometimes the attempt is made to give bending dimensions in the views of the structure, but as this greatly increases the difficulty of reading the drawing it is not good practice.

The usual symbol for concrete in section is used very commonly for reinforced concrete with the reinforcing-bar sections represented by heavy black dots, and the bars parallel to the section by dashed or full lines. This method, however, gives a very confused appearance. The reinforcing bars can be shown in place much more clearly if the concrete is represented by an even tint instead of the regular symbol. This tint may be made by section lining in colored ink or in very dilute black ink or, if the tracing is made on the smooth side of the cloth or if pencil drawings on vellum or cloth are

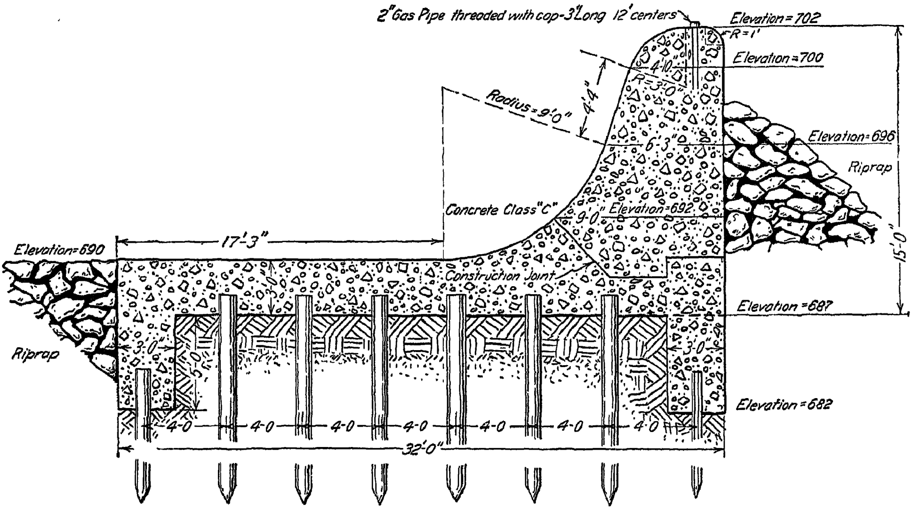


FIG. 960.—Masonry section; weir dam.

employed, by stumping the back with soft pencil. Any one of these methods gives a light blue tint on the blueprint and enables the details of the reinforcing, which is the important item, to be shown clearly. The two methods are shown side by side in Fig. 959.

Drawings of reinforced-concrete structures should contain, in tabular form, beam schedules, slab schedules and column schedules as well as bar schedules.

Certain classes of engineering structures involve much freehand rendering, and the ease of reading (usefulness) depends upon the care with which this rendering is done.

The section of a submerged weir, Fig. 960, illustrates a case in which there is comparatively little mechanical execution. Any means of bringing out the construction, such as surface shading or the use of solid black, is legitimate.

PROBLEMS

The problems following will illustrate the fundamentals of structural drawing. The dimensions of rolled shapes may be obtained from *Steel Construction*, the handbook of The American Institute of Steel Construction. Standard beam connections are given in Fig. 1061, page 605. Refer to Chap. XV for welding symbols.

1. Make a detail working drawing of the following structural member:

Two L5 × 3 × ¼ × 10′-0″ back to back, the 5″ legs outstanding. Five shop rivets on 2′-0″ centers in 3″ legs as follows: gage, 1¼″; end of member to first rivethole, 1′-0″. Two field rivetholes in each 5″ outstanding leg as follows: gage, 3″; one rivethole 3″ from each end of member. Size of rivets ⅝″.

2. Fig. 961. Make assembly working drawing of triple-effect evaporator support.

3. Fig. 961. Make detail drawings, with bill of material, ⅝″ rivets in 11/16″ holes; ¾″ field bolts in 13/16″ holes.

4. Fig. 961. Redesign for welded construction and make welding drawing.

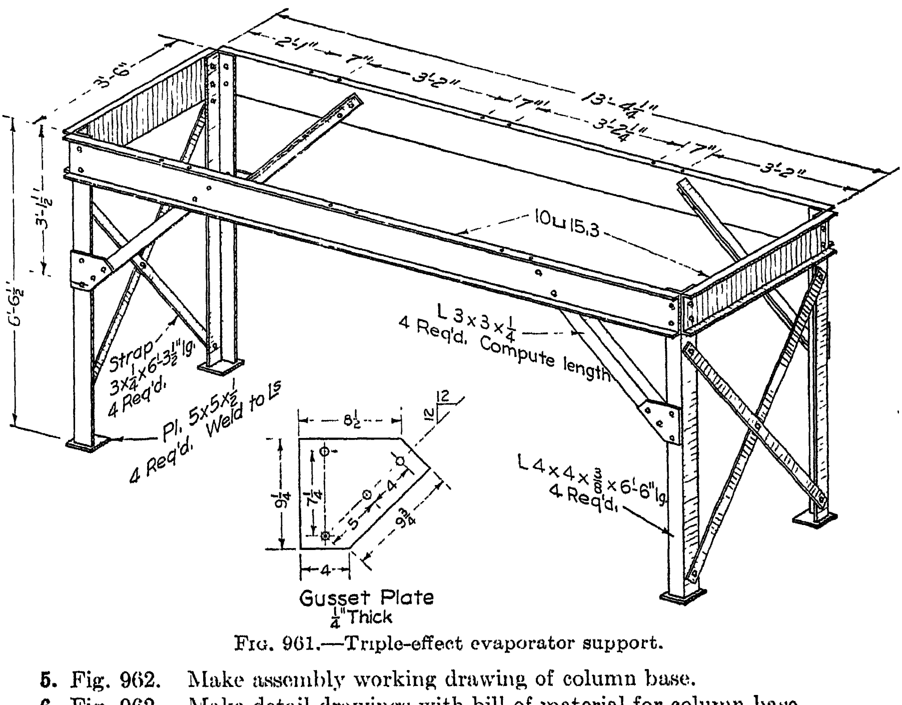


Fig. 961.—Triple-effect evaporator support.

5. Fig. 962. Make assembly working drawing of column base.

6. Fig. 962. Make detail drawings with bill of material for column base.

7. Fig. 963. Make assembly working drawing of crane-trolley-frame support.

8. Fig. 963. Make detail drawings with bill of material.

9. Fig. 947. Redesign, using modern connectors for fastening members.

10. Make an assembly working drawing of an English roof truss, using span and rise dimensions from Fig. 953. Bottom chord: 2 angles 4 × 4 × ⅜ back to back with ⅜ spacers; top chord members: 2 angles 3 × 3 × ⅜, back to back, with ⅜ × 6 plate; compression members: 2 angles 2 × 2 × ¼; tension members: 1 angle 2 × 2 × ¼; ⅝ rivets throughout. Provide 9/16″ holes in top chord for purlins.

11. Fig. 917. Make detail drawings with bill of material and rivet list for Prob. 10.

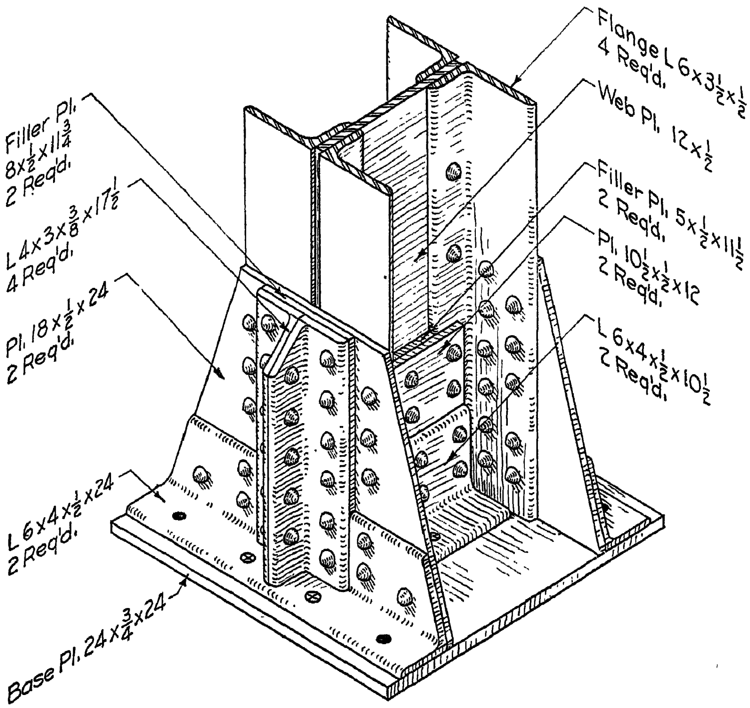


FIG. 962.—Column base.

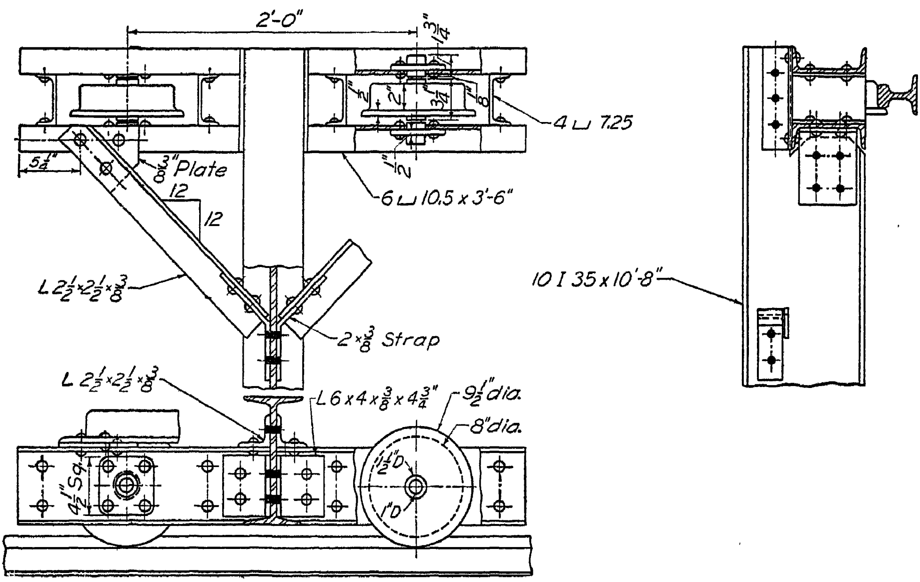


FIG. 963.—Crane trolley-frame support.

CHAPTER XXVI

MAP AND TOPOGRAPHIC DRAWING

433. Thus far in our consideration of drawing as a graphic language we have had to represent the three dimensions of an object either pictorially or, in the usual case, by drawing two or more views of it. In map drawing, that is, the representation of features on parts of the earth's surface, there is the distinct difference that the drawing is complete in one view, the third dimension, the height, being either represented on this view or omitted as not required for the particular purpose for which the map was made.

The surveying and mapping of the site is the first preliminary work in engineering projects, and it is desirable that all engineers should be familiar with the methods and symbols used in this branch of drawing. Without considering the practice of surveying and plotting or the various methods used by the cartographers in projecting the curved surface of the earth on a plane, we are interested in the use and details of execution of plats and topographic maps.

434. Classification.—The content or information on maps may be classified in general under three divisions:

1. The representation of imaginary lines, such as divisions between areas subject to different authority or ownership, either public or private; or lines indicating geometric measurements on the land, on the sea and in the air. In this division may be included plats or land maps, farm surveys, city subdivisions, plats of mineral claims and nautical and aeronautical charts.
2. The representation of real or material features or objects within the limits of the tract, showing their relative location or size and location, depending upon the purpose of the map. When relative location only is required the scale may be small, and symbols employed to represent objects, as houses, bridges or even towns. When the size of the objects is an important consideration the scale must be large and the map becomes a real orthographic top view.
3. The representation of the relative elevations of the surface of the ground. Maps with this feature are called "relief maps" or, if contours are used with elevations marked on them, "contour maps." Hydrographic maps show fathom-line depth curves.

Various combinations of these three divisions are required for different purposes. Classified according to their purpose, maps may be (*a*) geographic, (*b*) topographic, (*c*) hydrographic, (*d*) nautical, (*e*) aeronautical, (*f*) cadastral, (*g*) engineering, (*h*) photogrammetric and (*i*) military.

a. Geographic maps include large areas and consequently must be to small scale. They show important towns and cities, streams and bodies of water, political boundaries and relief.

b. *Topographic maps* are complete descriptions of certain areas and show to larger scale the geographical positions of the natural features and the works of man. The relief is usually represented by contours.

c. *Hydrographic maps* deal with information concerning bodies of water, as shore lines, sounding depths, subaqueous contours, navigation aids and water control.

d. *Nautical maps* or charts are designed to show aids to water navigation, as buoys, beacons, lighthouses, lanes of traffic, sounding depths, shoals and radio compass stations.

e. *Aeronautical maps* or charts provide prominent landmarks of the terrain and accentuate the relief by layer tints, hachures and 500- or 1,000-foot contours as aids to air navigation.

f. *Cadastral maps* are very accurate control maps for cities and towns, made to large scale with all features drawn to size. They are used to control city development and operation, particularly taxation.

g. *Engineering maps* are working maps for engineering projects and are designed for specific purposes to aid construction. They provide accurate horizontal and vertical control data and show objects on the site or along the right of way.

h. *Photogrammetric maps* represent features on the earth's surface from terrestrial and aerial photographs. These photographs are perspectives from which orthographic views are obtained by stereoscopic instruments. Ground control stations are necessary to bring the photographs to a required datum.

i. *Military maps* are designed to contain information of military importance in the area represented.

435. Plats.—A map plotted from a plane survey, and having the third dimension omitted, is called a "plat" or "land map." It is used in the description of any tract of land when it is not necessary to show relief, as in such typical examples as a farm survey or a city plat.

The plotting is done from field notes by (1) latitudes and departures, (2) bearings and distances, (3) azimuths and distances, (4) deflection angles and distances or (5) rectangular coordinates. Or the plotting is done by the total latitude and departure from some fixed origin for each separate point, which method is necessary to distribute plotting errors over the entire survey. Angles are laid off from bearing or azimuth lines by plotting the tangent of the angle or the sine of half the angle, by sine-and-cosine method, or by an accurate protractor.

The first principle to be observed in the execution of this kind of drawings is *simplicity*. Its information should be clear, concise and direct. The lettering should be done in single stroke, and the north point and border should be of the simplest character. The day of the intricate border corner, elaborate north point and ornamental title is, happily, past, and all such embellishments are rightly considered not only as a waste of time but as being in very bad taste.

436. Plat of a Survey.—The plat of a survey should give clearly all the information necessary for the legal description of the parcel of land. It should contain

1. Direction and length of each line.
2. Acreage.

3. Location and description of monuments found and set.
4. Location of highways, streams, rights of way and any appurtenances required.
5. Official division lines within the tract.
6. Names of owners of abutting property.
7. Title, scale, date.
8. North point with certification of horizontal control.
9. Plat certification properly executed.
10. Reference to state plane-coordinate system.

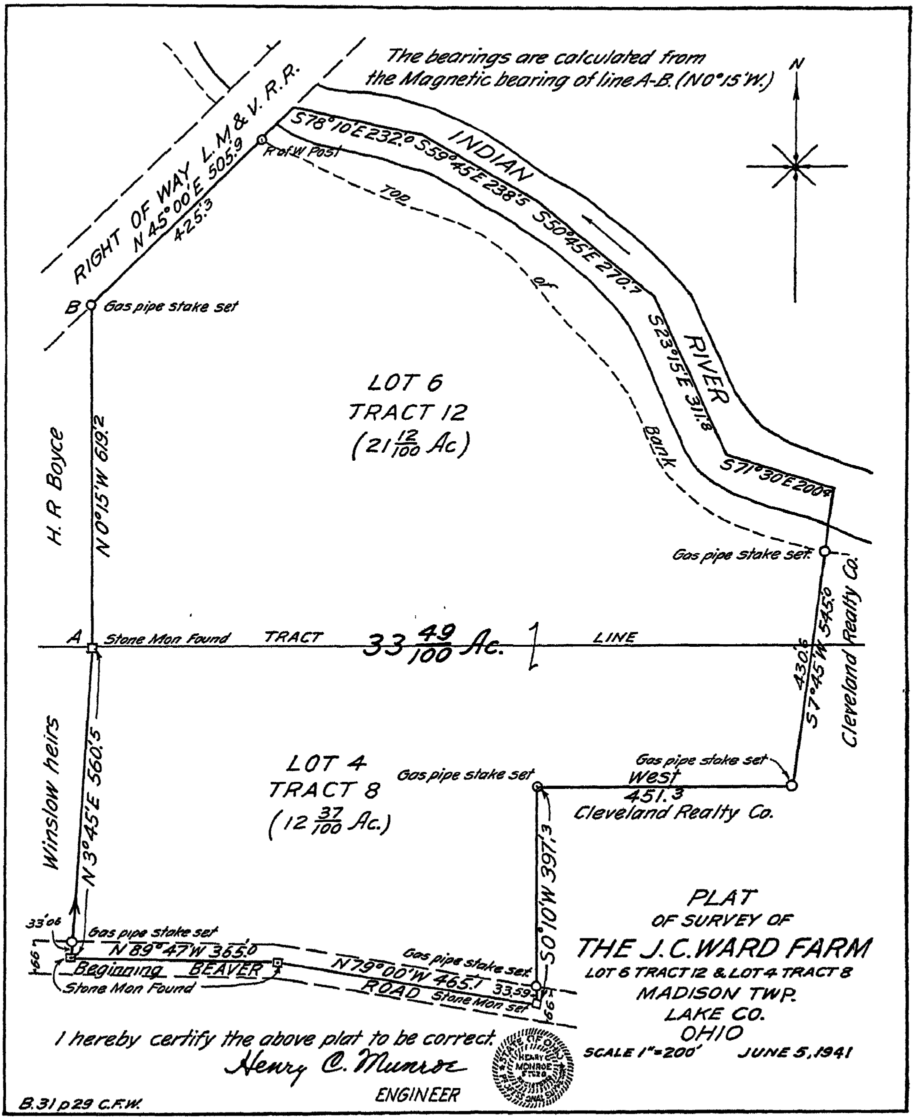


Fig. 964.—Plat of a survey.

Figure 964 illustrates the general treatment of this kind of drawing. It is almost always traced and blueprinted, and no water lining of streams

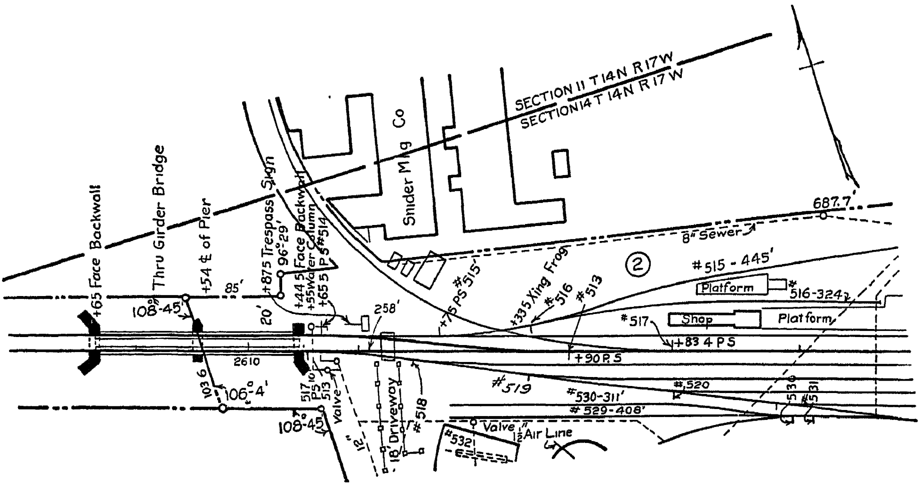


Fig. 965.—Part of a railroad property map.

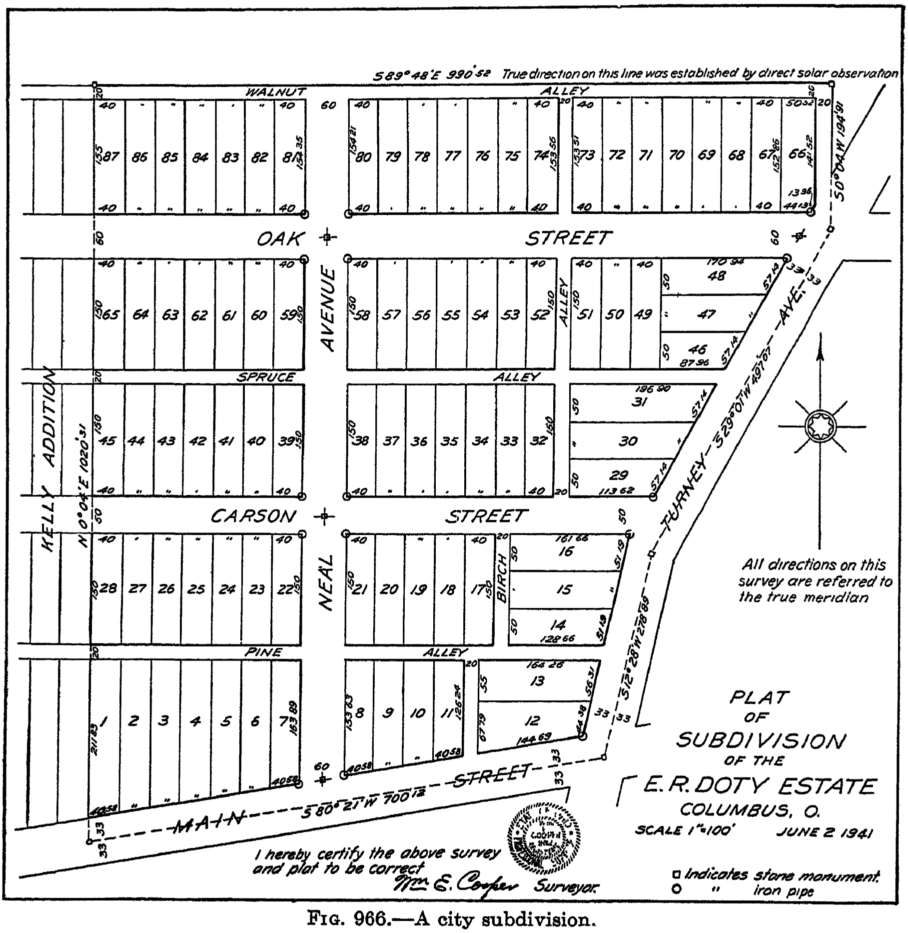


Fig. 966.—A city subdivision.

or other elaboration should be attempted. It is important to observe that the size of the lettering used for the several features must be in proportion to their importance.

437. A Railroad Property Map.—Of the many kinds of plats used in industrial work one only is illustrated here, a portion of a railway situation or station map, Fig. 965. This might represent also a plant-valuation map, a type of plat often required. The information on such maps varies

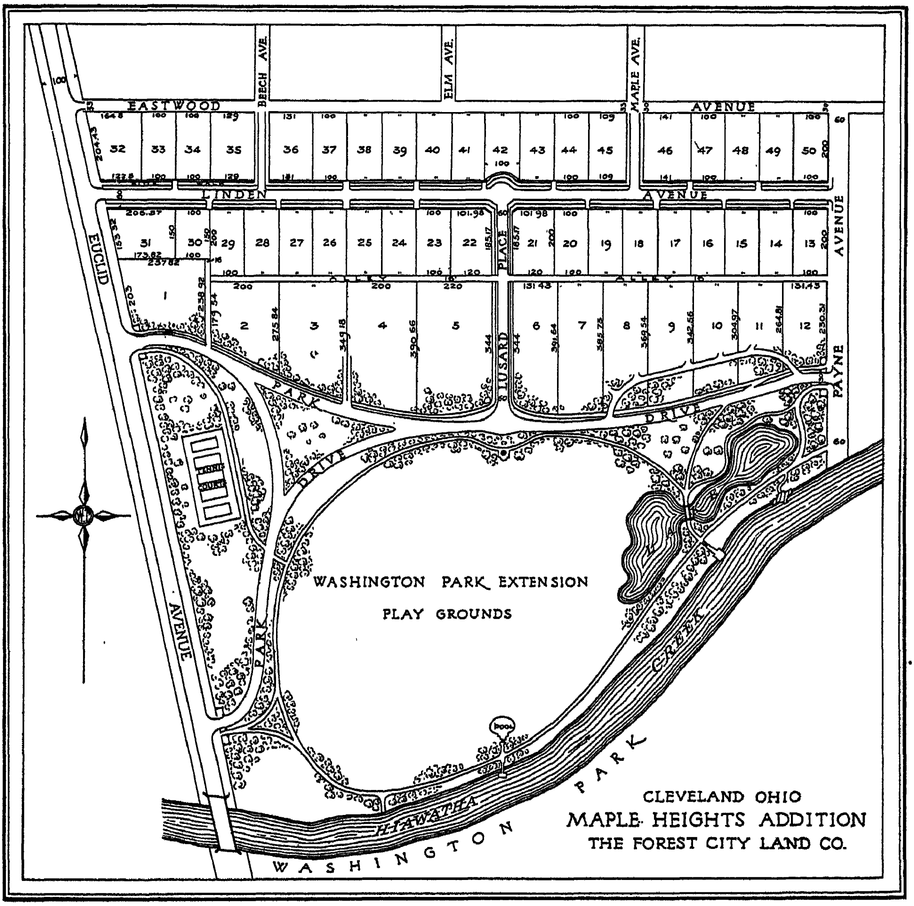


FIG. 967.—A real estate display map.

to meet the requirements of particular cases. In addition to the preceding list, it might include such items as pipe lines, fire hydrants, location and description of buildings, railroads and switch points, outdoor-crane runways, etc.

438. Plats of Subdivisions.—The plats of subdivisions and allotments in cities are filed with the county recorder for record and must be very complete in their information concerning the location and size of the various lots and parcels composing the subdivisions, Fig. 966. All monuments set

should be shown and all directions and distances recorded, so that it will be possible to locate any lot with precision.

Sometimes landowners desire to use these maps in display to prospective buyers and often include a blueprint or black-line print bound with the deed. Some degree of embellishment is allowable, but care must be taken

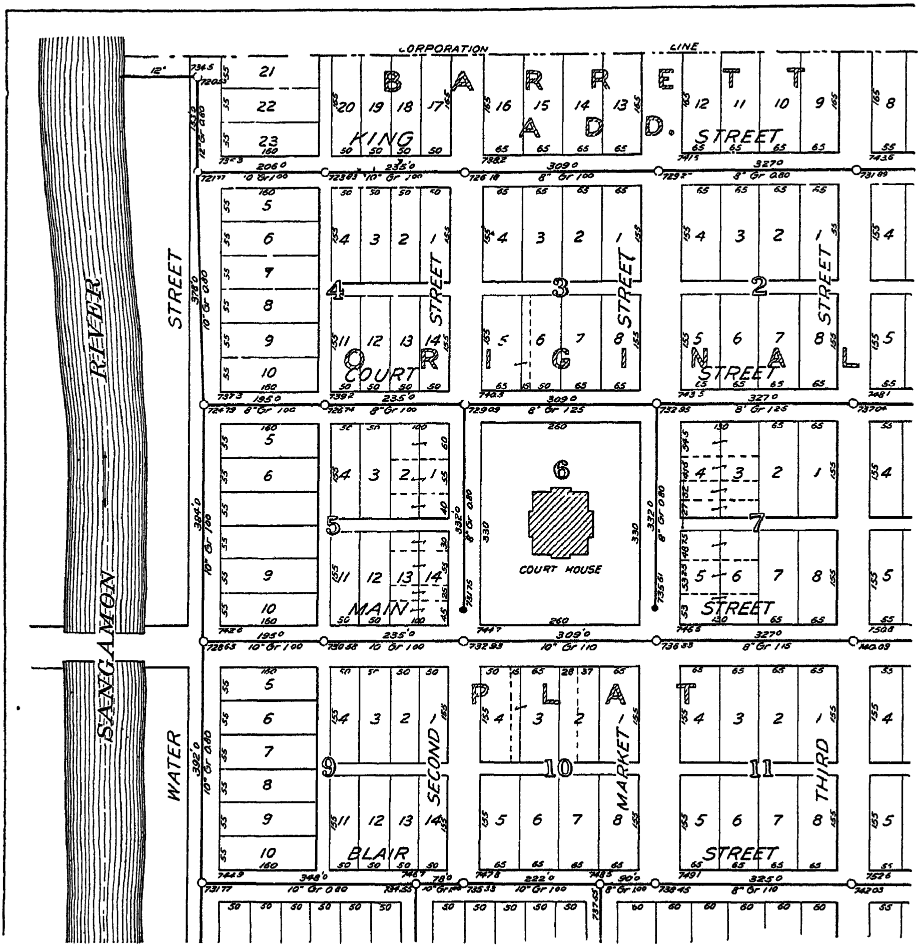


FIG. 968.—A sewer map.

not to overdo the ornamentation. Figure 967 is an example showing an acceptable style of execution and finish.

439. City Plats.—Under this head are included chiefly maps or plats drawn from subdivision plats or other sources for the record of city improvements. These plats are used to record a variety of information, such as the location of sewers, water mains, gas, power and steam lines, telephone installations and street improvements.

The records maintained on these maps provide valuable data for assessments and constitute progress reports on the growth of a city. As they are

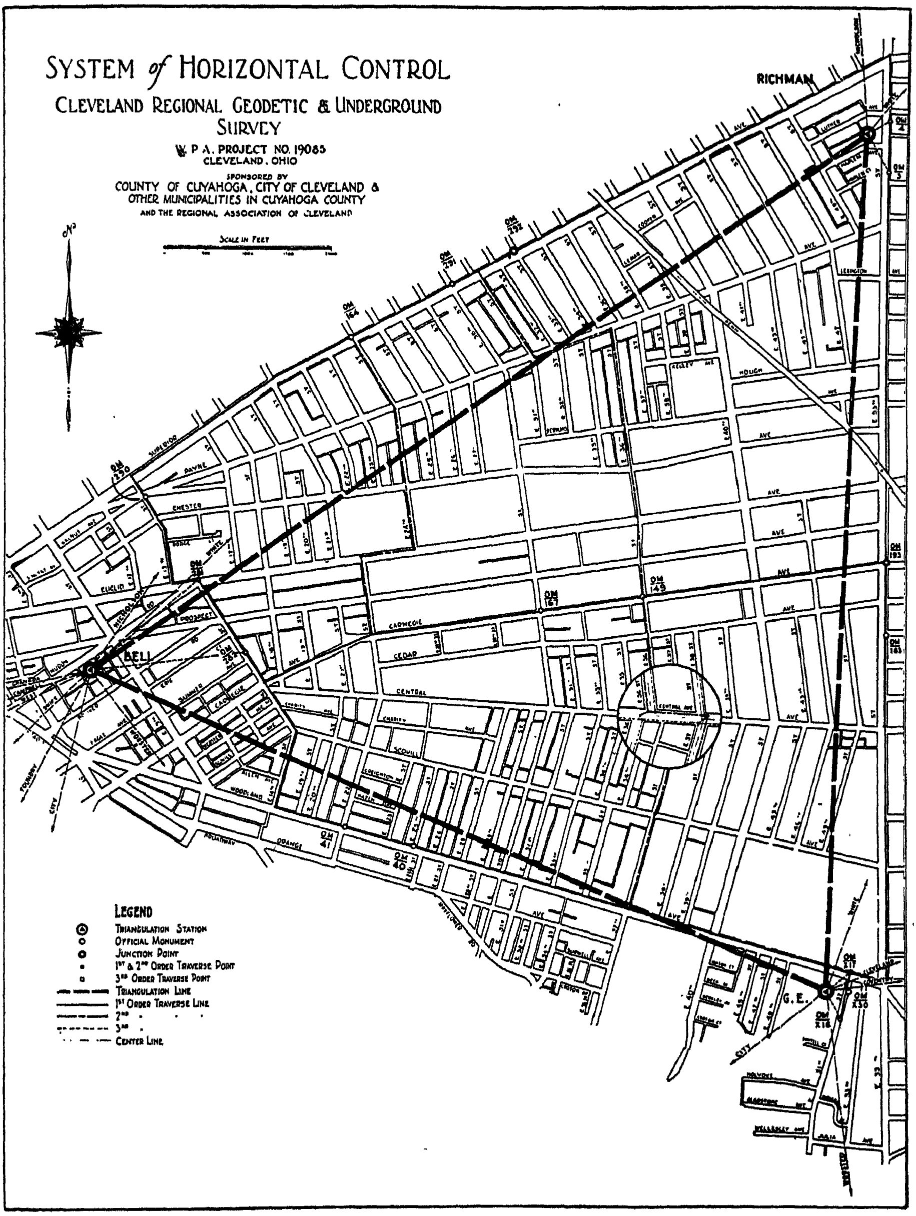


FIG. 969.—Horizontal control.

made for a definite purpose they should not contain unnecessary information and hence will not include all the details as to sizes of lots, which are given on subdivision plats, but they should carry both horizontal and vertical

control points for proper location of utilities. They are usually made on mounted paper and should be to a scale large enough to show clearly the features required; 100′ and 200′ to the inch are common scales, and as large as 50′ is sometimes used. For smaller cities the entire area may be covered by one map; for larger cities the maps are made in convenient sections so as to be filed readily.

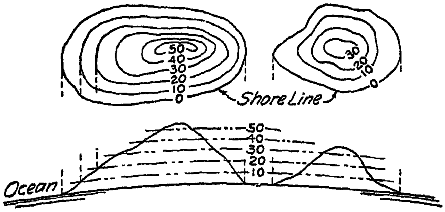


FIG. 970.—Contours.

A study of Fig. 968, a sewer map, will show the general treatment of such plats. The appearance of the drawing is improved by adding shade lines on the lower and right-hand side of the blocks, that is, treating the streets and water features as depressions. A few of the more important public buildings are shown, to facilitate reading. The various wards, subdivisions or districts may be shown by large outline letters or numerals as illustrated in the figure. Contours are often put on these maps in red or brown ink, either on the original or sometimes on a positive print from it.

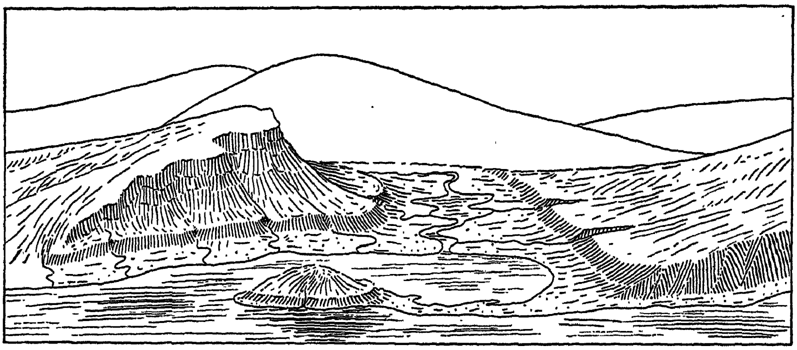


FIG. 971.—Perspective view.

Figure 969 shows a modern system of horizontal control used by the city of Cleveland for a geodetic and underground survey.

440. Topographic Drawing.—As before defined, a complete topographic map would contain:

1. The imaginary lines indicating the divisions of authority or ownership.
2. The geographical position of both the natural features and the works of man. They may also include information in regard to the vegetation.
3. The relief, or indication of the relative elevations and depressions. The relief, which is the third dimension, is represented in general either by contours or by hill shading.

441. Contours.—A contour is an imaginary line on the surface of the ground which, at every point, passes through the same elevation; thus the shore line of a body of water represents a contour. If the water should rise 1 foot the new shore line would be another contour, with 1-foot "contour

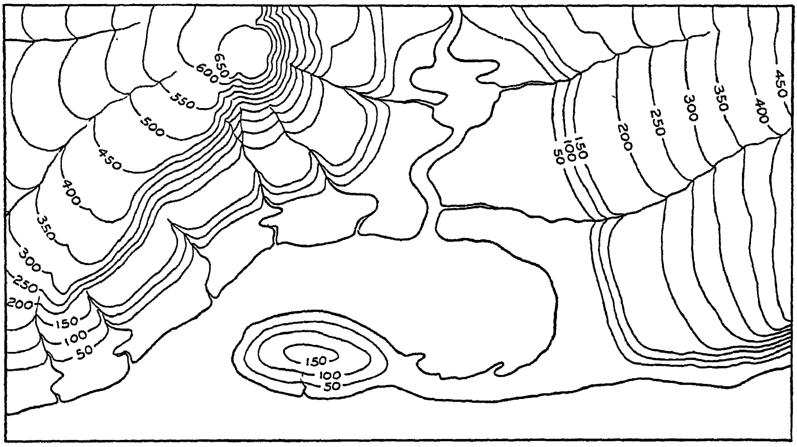


FIG. 972.—Application of contour lines.

interval." A series of contours may thus be illustrated approximately by Fig. 970.

Figure 971 is a perspective view of a tract of land. Figure 972 is a contour map of this area, and Fig. 973 is the same surface shown with hill

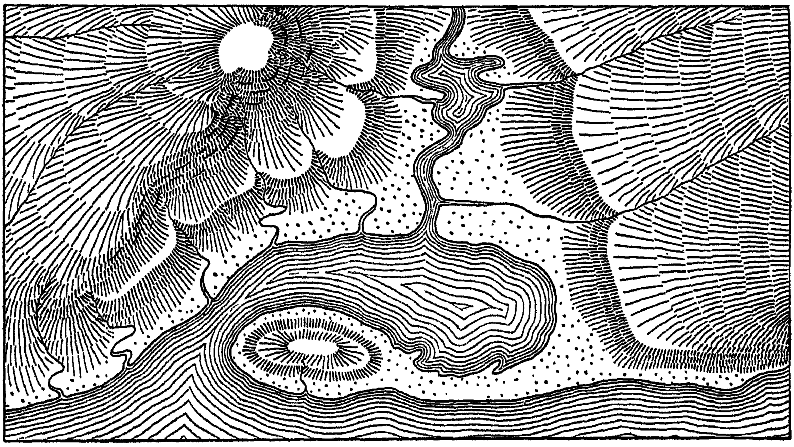


FIG. 973.—Application of hachures for hill shading.

shading by hachures. Contours are drawn as fine, full lines, with every fifth one of heavier weight and with the elevations in feet marked on them at intervals, usually with the sea level as datum. They may be drawn with a swivel pen, Fig. 1034, or a fine pen such as Gillott's 170 or Esterbrook's 356. On paper drawings they are usually made in brown.

Figure 974 is a topographic map of the site of a proposed filtration plant and illustrates the use of the contour map as the necessary preliminary drawing for engineering projects. Often on the same drawing there are shown, by lines of different character, both the existing contours and the required finished grades.

442. Hill Shading.—The showing of relief by means of hill shading gives a pleasing effect but is very difficult of execution, does not give exact elevations and would not be applied on maps to be used for engineering purposes.

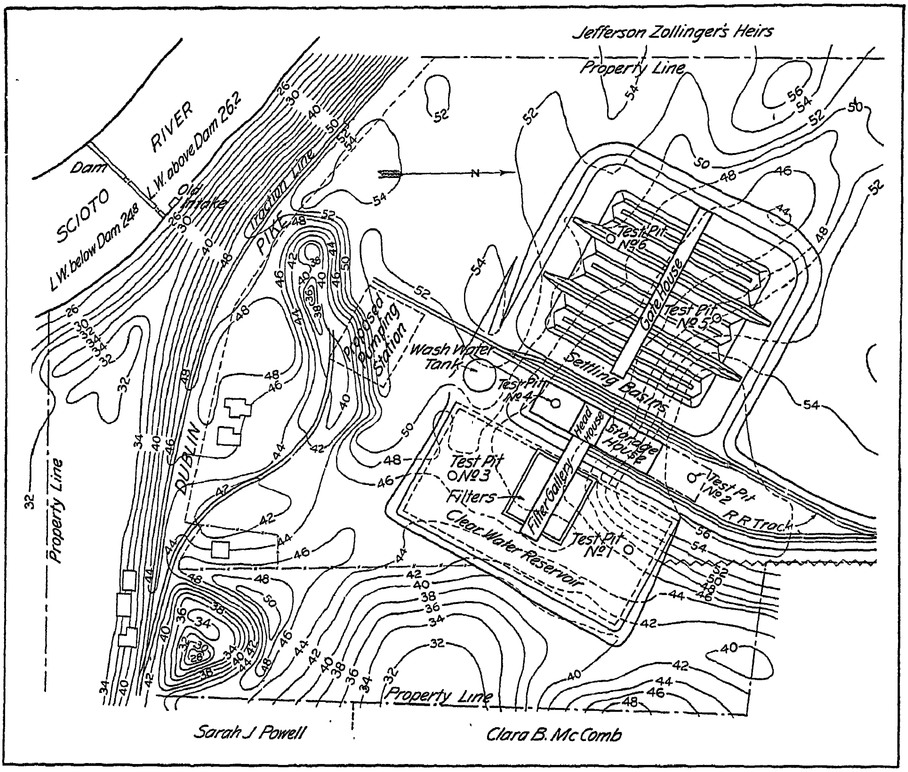


Fig. 974.—Contour map for an engineering project.

It may sometimes be used to advantage in reconnaissance maps or in small-scale maps for illustration. There are several systems, of which hachuring, as shown in Fig. 973, is the commonest. The contours are sketched lightly in pencil and the hachures drawn perpendicular to them, starting at the summit and grading the weight of line to the degree of slope. A scale of hachures to use for reference is often made, graded from black for 45° to white for horizontal. The rows of strokes should touch the pencil line to avoid white streaks along the contours. Two other systems in use are the horizontal, or English system, using graded hachure lines parallel to the contours, and the oblique illumination, or French system, using hachures graded to give sunlight effect as well as the degree of slope.

443. Water Lining.—On topographic maps made for display or reproduction the water features are usually finished by "water lining," that is, by running a system of fine lines parallel to the shore lines, either in black or in blue (it must be remembered that blue will not photograph for reproduction or print well from a tracing). Poor water lining will ruin the appearance of an otherwise well-executed map, and it is better to omit it rather than do it hastily or carelessly. The shore line is drawn first, and the water lining done with a fine mapping pen, the draftsman always drawing toward his body, with the preceding line to his left. The first line should follow the shore line very closely, and the distances between the succeeding lines should be gradually increased and the irregularities lessened. Sometimes the weight of lines is graded as well as the intervals, but this is a very difficult operation and is not necessary for the effect. A common mistake is to make the lines excessively wavy or rippled.

In water lining a stream of varying width, the lines are not to be crowded so as to be carried through the narrower portions, but corresponding lines must be brought together in the middle of the stream as illustrated in Fig. 973. Care should be taken to avoid spots of sudden increase or decrease in spacing.

444. Topographic Symbols.—The various symbols used in topographic drawing may be grouped under four heads:

1. Culture, or the works of man.
2. Relief—relative elevations and depressions.
3. Water features.
4. Vegetation.

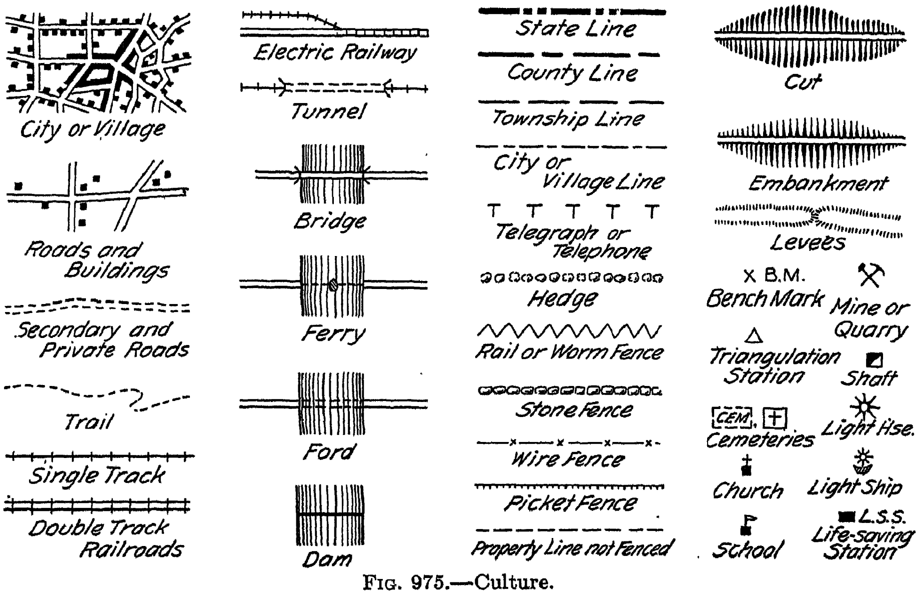


FIG. 975.—Culture.

When color is used the culture is done in black, the relief in brown, the water features in blue, and the vegetation in black or green.

These symbols, used to represent characteristics on the earth's surface, are made, when possible, to resemble somewhat the features or objects represented as they would appear either in plan or in elevation. No attempt

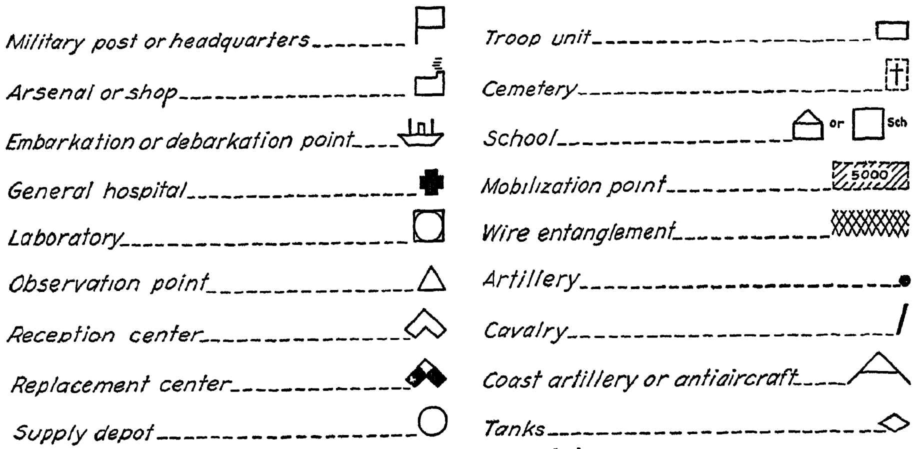


FIG. 976.—Military symbols.

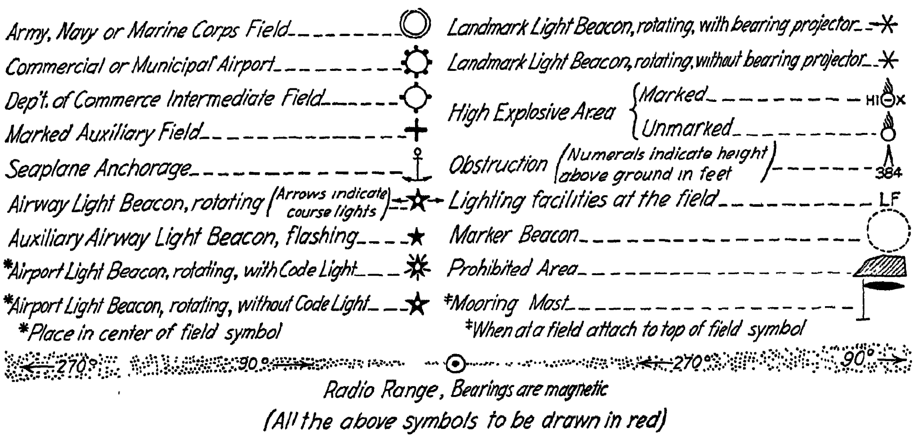


FIG. 977.—Aviation symbols.

is here made to give symbols for all the features that might occur in a map; indeed one may have to invent symbols for some particular locality.

Figure 975 illustrates a few of the conventional symbols used for culture or the works of man, and no suggestion is needed as to the method of their execution. When the scale used is large, houses, bridges, roads and even tree trunks can be plotted so that their principal dimensions can be scaled. The landscape architect is interested not only in the size of the trunk of a tree but also in the spread of its branches. A small-scale map can give by its symbols only the relative locations.

Some military symbols are shown in Fig. 976, symbols for aerial navigation in Fig. 977, and aids to water navigation in Fig. 978, all as adopted by the United States Board of Surveys and Maps. Figure 979 gives the

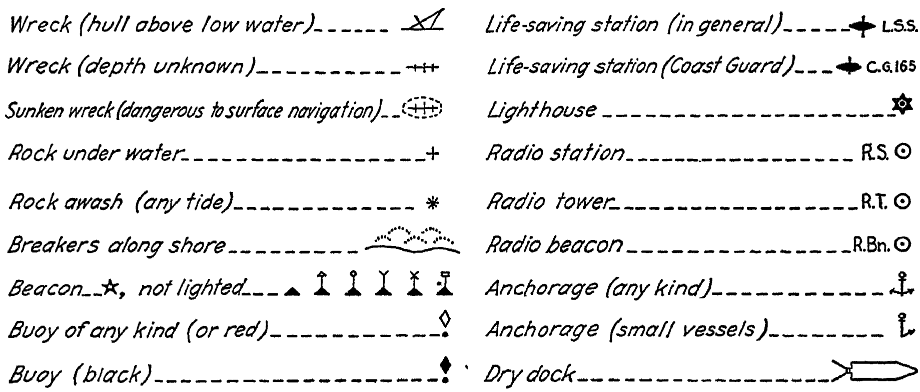


FIG. 978.—Aids to water navigation.

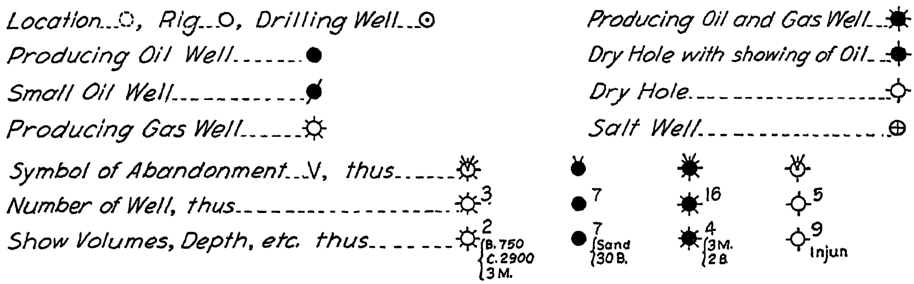


FIG. 979.—Oil and gas symbols.

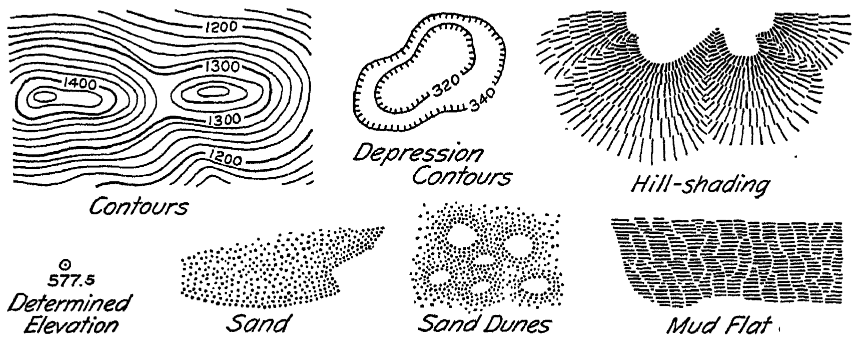


FIG. 980.—Relief.

standard symbols used in the development of oil and gas fields, Fig. 980 the symbols used to show relief, Fig. 981 water features, and Fig. 982 some of the commoner symbols for vegetation and cultivation.

The draftsman should keep in mind the purpose of the map and in some measure indicate the relative importance of the features, varying their

prominence by the weights of lines used or sometimes by varying the scale of the symbol. For instance, in a map made for military maneuvering a cornfield might be an important feature; or in maps made to show the location of special features, such as fire hydrants, these objects would be indi-

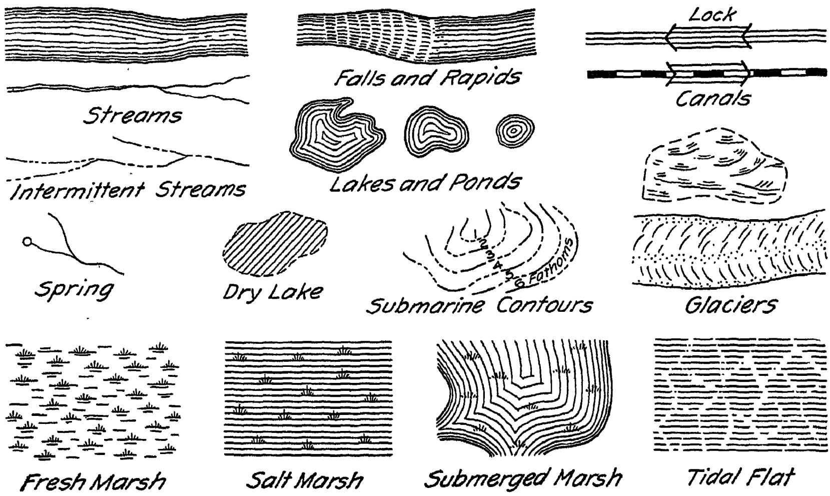


FIG. 981.—Water features.

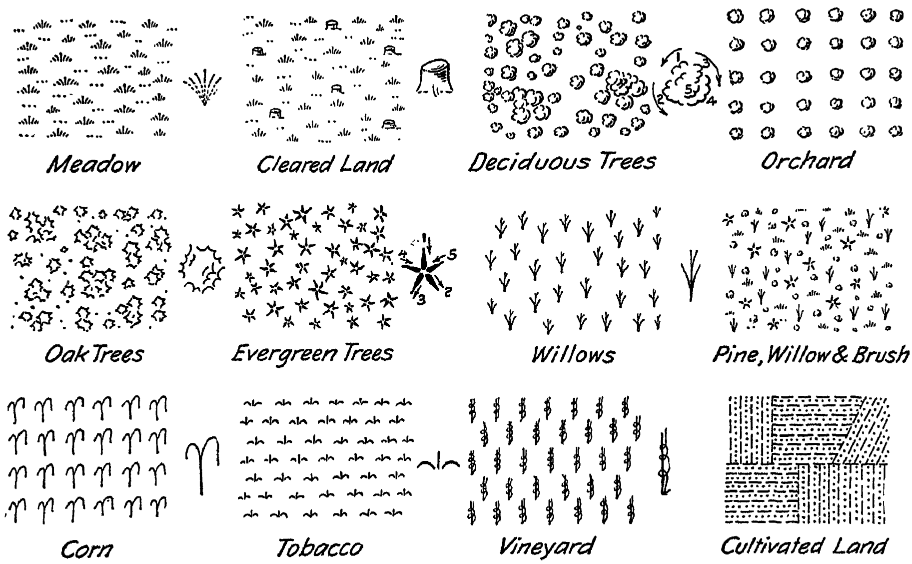


FIG. 982.—Vegetation.

cated very plainly. The map of an airport or a golf course would contain emphasized features. This principle calls for some originality to meet various cases.

A common fault of the beginner is to make symbols too large. The symbols for grass, shown under "meadow," Fig. 982, if not made and spaced

correctly will spoil the entire map. This symbol is composed of from five to seven short strokes radiating from a common center and starting along a horizontal line as shown in the enlarged form, each tuft beginning and ending with a mere dot. Always place the tufts with the bottom parallel to the border and distribute them uniformly over the space, but not in rows. A few incomplete tufts or rows of dots improve the appearance. Grass-tuft symbols should never be as heavy as tree symbols. In drawing the symbol for deciduous trees the sequence of strokes shown should be followed.

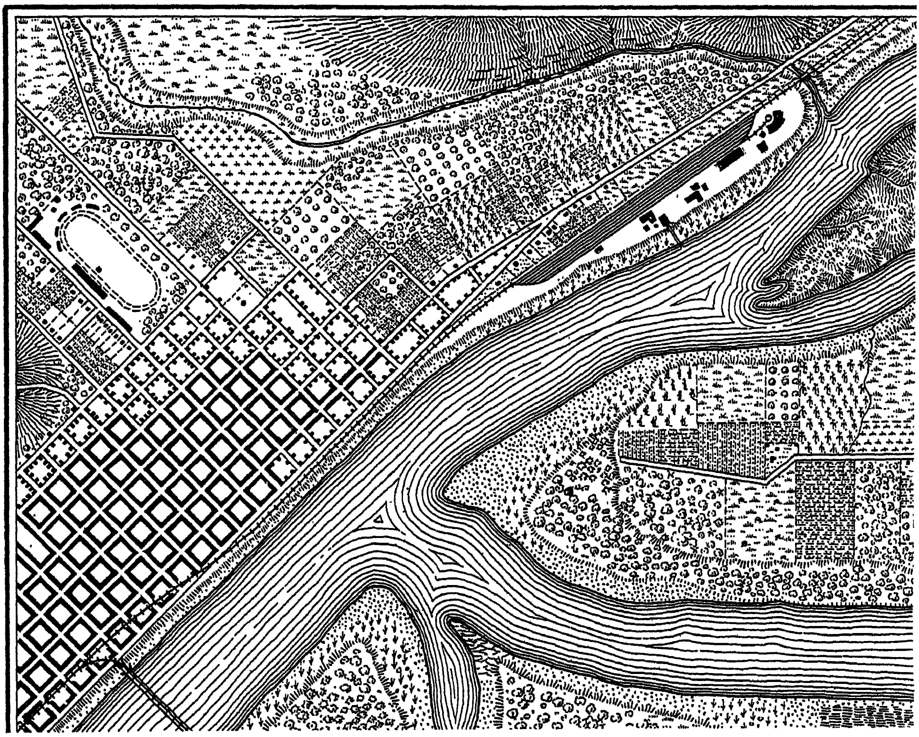


FIG. 983.—Part of a topographic map.

The topographic map, Fig. 983, is given to illustrate the general execution and placing of symbols.

The well-known maps of the U. S. Coast and Geodetic Survey and the Geological Survey illustrate the application of topographic drawing. The *quadrangle sheets* issued by the topographic branch of the U. S. Geological Survey are excellent examples and so easily available that every draftsman should be familiar with them. These sheets represent 15 minutes of latitude and 15 minutes of longitude to the scale of 1:62,500 or approximately 1 inch to the mile. The entire United States is being mapped by the department in cooperation with the different states, and in 1941, with the work of 18 states finished, almost 50 per cent of the country had been completed.

This work is now greatly facilitated through the use of aerial photography. Much territory in the West and South has been mapped ½ inch to the mile, and earlier some in the West was mapped ¼ inch to the mile. These maps may be secured for 10 cents each (not stamps) by addressing The Director, U.S. Geological Survey, Washington, D.C., from whom information as to the completion of any particular locality or the progress in any state may be had.

445. Landscape Maps.—A topographic map made to a relatively large scale and showing all details is called a "landscape map." Such maps are required by architects and landscape gardeners for use in planning buildings to fit the natural topographic features and for landscaping parks, playgrounds and private estates. These are generally maps of small areas, and a scale of $1'' = 20'$ to $1'' = 50'$, depending upon the amount of detail, is used.

The contour interval varies from 6 inches to 2 feet according to the ruggedness of the surface. The commonest interval is 1 foot. These maps are often reproduced in black-line prints, upon which contours in different color are drawn to show the landscape treatment proposed. Natural features and culture are added in more detail than on ordinary topographic maps. Trees are designated as to size, species and sometimes spread of branches and condition. It is often necessary to invent symbols suitable for the particular survey and to include a key or legend on the map. Roads, walks, streams, flower beds, houses, etc., should be plotted carefully to scale, so that measurements can be taken from them.

446. Colors.—Instead of using colored inks, which are thin and unsatisfactory to handle in the pen and do not photograph or blueprint well, it is much better to use water colors for contours, streams and other colored features in topographic mapping. For contours, burnt sienna, either straight or darkened with a drop of black, and mixed rather thick; for streams, Prussian blue; and for features in red, alizarin crimson all work well in either crow-quill or contour pen and make good blueprints. Colors in tubes are more convenient than those in cakes or pans.

447. Lettering.—The style of lettering on a topographic map will depend upon the purpose for which the map is made. If it is for construction purposes, such as a contour map for the study of municipal problems, street grades, plants or railroads, the single-stroke Gothic and Reinhardt is to be preferred. For a finished map, vertical Modern Roman letters as shown on page 57, capitals for important land features and lower case for less important features, such as small towns and villages; inclined Roman and stump letters, as shown on page 59, for water features, should be used. The scale should always be drawn as well as stated.

448. Titles.—The standard letter for finished map titles is the Modern Roman. The design should be symmetrical, with the heights of the letters

proportioned to the relative importance of the line. A map title should contain as many as are necessary of the following items:

1. Kind—"Map of," etc.
2. Name.
3. Location of tract.
4. Purpose, if special features are represented.
5. For whom made.
6. Engineer in charge.
7. Date (of survey).
8. Scale—stated and drawn; contour interval; datum.
9. Authorities.
10. Legend or key to symbols.
11. North point, with certification of horizontal control.
12. Certification, properly executed.
13. Reference to state plane-coordinate system.

449. Profiles.—Perhaps no kind of drawing is used more by civil engineers than the ordinary profile, which is simply a vertical section taken along a given line, either straight or curved. Such drawings are indispensable in problems of railroad construction, highway and street improvements, sewer construction and many other problems where a study of the surface of the ground is required. Very frequently engineers other than civil engineers are called upon to make these drawings. Several different types of profile and cross-section paper are in use, and their descriptions may be found in the catalogues of the various firms dealing in drawing materials. One type of profile paper in common use is known as "Plate A" and has 4 divisions to the inch horizontally and 20 to the inch vertically. Other divisions in use are 4 × 30 to the inch and 5 × 25 to the inch. At intervals, both horizontally and vertically, somewhat heavier lines are made in order to facilitate reading.

Horizontal distances are plotted as abscissas and elevations as ordinates. Since the vertical distances represent elevations and are plotted to larger scale, a vertical exaggeration is obtained that is very useful in studying profiles that are to be used for establishing grades. The vertical exaggeration is sometimes confusing to the layman or inexperienced engineer, but ordinarily a profile will fail in the purpose for which it was intended if the horizontal and vertical scales are the same. Again, the profile unless so distorted would be a very long and unwieldy affair, if not entirely impossible to make. The difference between profiles with and without vertical exaggeration is shown in Figs. 984 and 985.

Figure 986 is a portion of a typical State Highway *Alignment and Profile Sheet*, plotted to a horizontal scale of 1″ = 100′ and a vertical scale of 1″ = 10′. For this type of drawing, tracing cloth is furnished with the coordinates printed in red on the back so that any changes or erasures on the profile will not damage the coordinate lines. Lettering or other features are sometimes brought out by erasing the lines on the back. This sheet is one of a set of drawings used for estimating cost, and by the contractor as a

working drawing during construction. Other drawings in the set consist of a title sheet showing the location plan with detours provided; a sheet indicating conventional signs; a sheet giving an index to bound sheets; and

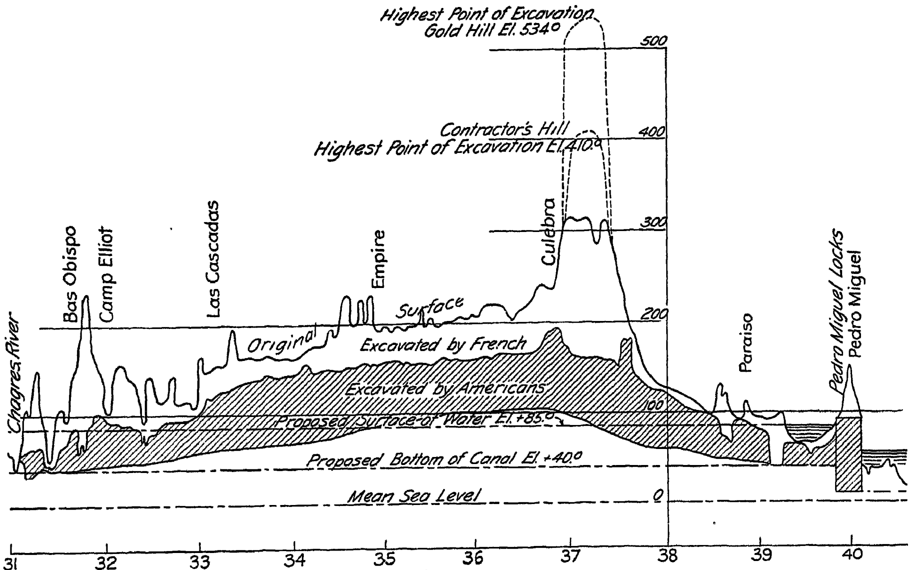


FIG. 984.—Profile (vertical scale 50 times horizontal).

a sheet with space reserved for declarations of approval and signatures of proper officials.

Also there are sheets of cross sections taken at each 100-foot station and all necessary intermediate stations to estimate earthwork for grading;

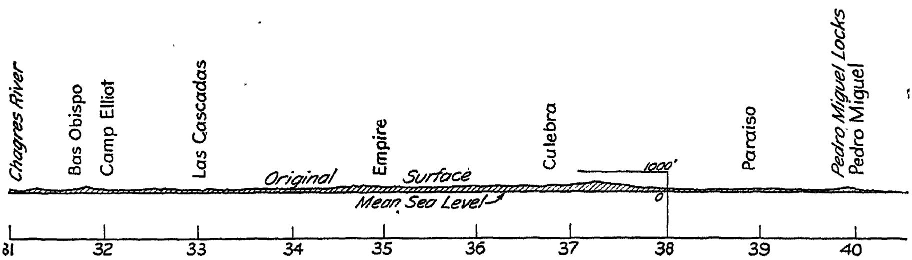
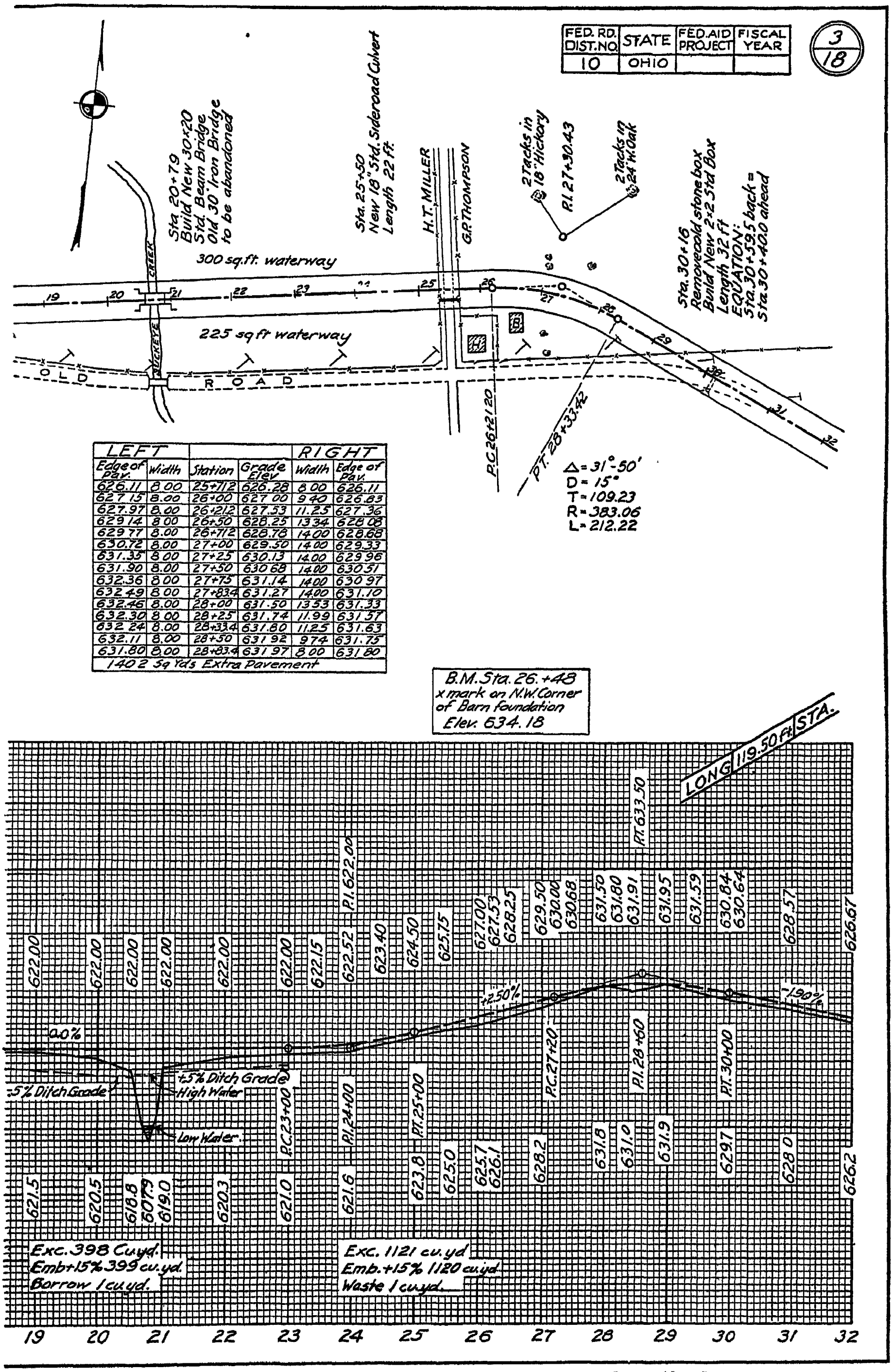


FIG. 985.—Profile (vertical and horizontal scales equal).

working drawings for drainage structures; site plans for bridges; specifications for guard rails and other safety devices; standard or typical road sections for cut and fill and various other conditions; and finally summary sheets for separate tables and quantities of materials for roadway, pavement and structures.



LEFT				RIGHT	
Edge of Pav.	Width	Station	Grade Elev	Width	Edge of Pav.
626.11	8.00	25+71.2	626.28	8.00	626.11
627.15	8.00	26+00	627.00	9.40	626.83
627.97	8.00	26+21.2	627.53	11.25	627.36
629.14	8.00	26+50	628.25	13.34	628.08
629.77	8.00	26+71.2	628.78	14.00	628.68
630.72	8.00	27+00	629.50	14.00	629.33
631.35	8.00	27+25	630.13	14.00	629.96
631.90	8.00	27+50	630.68	14.00	630.51
632.36	8.00	27+75	631.14	14.00	630.97
632.49	8.00	27+83.4	631.27	14.00	631.10
632.46	8.00	28+00	631.50	13.53	631.33
632.30	8.00	28+25	631.74	11.99	631.57
632.24	8.00	28+33.4	631.80	11.25	631.63
632.11	8.00	28+50	631.92	9.74	631.75
631.80	8.00	28+83.4	631.97	8.00	631.80
1402 Sq Yds Extra Pavement					

Fig. 986.—Part of a state highway alignment and profile sheet.

CHAPTER XXVII

CHARTS, GRAPHS AND DIAGRAMS

450. This chapter is given as an introduction to the use of graphical methods in tabulating data for analysis, solving problems and presenting facts. It will indicate to the prospective engineer the uses and value of this application of graphics and suggest his further study of the subject.

For the purpose of presenting a series of quantitative facts quickly, the graphical chart is the one best method. The statement, "it is easier to see than to think," meaning that with the majority of people the visual impression is the strongest form of appeal, expresses well the argument for this method of analysis. It is not to be supposed, however, that charts can be substituted for thinking, for really all they can do is to assist clear thinking by eliminating the tiring mental effort necessary in keeping in mind an involved series of figures. When properly constructed and thoroughly understood, charts, graphs and diagrams constitute a powerful tool for computation, analysis of engineering data and the presentation of statistics for comparison or prediction.

451. When classified as to use, charts, graphs and diagrams may be divided roughly into two classes: those used for purely technical purposes and those for popular appeal in advertising or the presentation of information. The engineer is concerned mainly with the first class, but he should have some acquaintance with the preparation and the influential possibilities of the second class. The aim here is to give a short study of the types with which engineers and those in allied professions should be familiar.

The construction of a graphical chart requires a fair degree of draftsmanship, but in engineering and scientific work the important considerations are judgment in the proper selection of coordinates, accuracy in plotting points and drawing the graph and an understanding of the functions and limitations of the resulting chart.

It is assumed that the reader is familiar with the use of rectangular coordinates and that the meaning of such terms as "axes," "ordinates," "abscissas," "coordinates," "variables," etc., is understood.

452. Titles and Notation.—The title is a very important part of a chart, and its wording should be studied until it is clear and concise. In every case it should contain sufficient description to tell what the chart is, the source or authority, the name of the observer and the *date*. Approved practice places the title at the top of the sheet, arranged in phrases symmetrically about a center line. If placed within the ruled space, a border line or box should set it out from the sheet. Each sheet of curves should have a title,

and when more than one curve is shown on a sheet, the different curves should be drawn so as to be easily distinguishable, by varying the character of the lines, using full, dotted and dot-and-dash lines, with a tabular key for identification, or by lettering the names of the curves directly along them. When the charts are not intended for reproduction, inks of different colors may be used.

453. Rectilinear Charts.—The rectilinear chart is made on a sheet ruled with equispaced horizontal lines crossing equispaced vertical lines. The

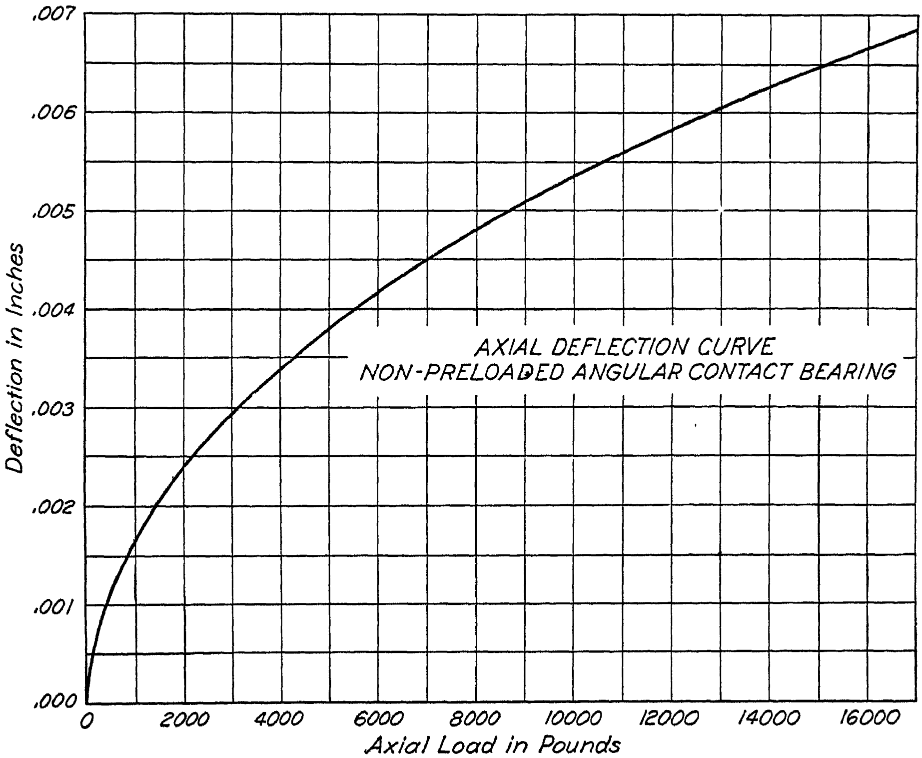


FIG. 987.—An engineering diagram.

spacing is optional but it is customary and convenient to use squares of $\frac{1}{20}$ inch with every fifth line heavier, to aid in plotting and reading. Sheets are printed with various other rulings, as 4, 6, 8, 12 and 16 divisions per inch.

As the greater part of chart work in experimental engineering is done on rectilinear graph paper the student should become familiar with this form of chart early in his course.

It is universal practice to use the upper right-hand quadrant for plotting experimental-data curves, making the lower left-hand corner the origin. In case both positive and negative values of a function are to be plotted, as is the case with many mathematical curves, it is necessary to place the origin so as to include all desired values.

Figure 987 shows a usual form of rectilinear chart, such as might be made on $8\frac{1}{2}'' \times 11''$ paper for inclusion in a written report.

454. Curves.—In drawing graphs from experimental data it is often a question whether the curve should pass through all the points plotted or strike a mean between them. In general, observed data not backed up by definite theory or mathematical law is shown by connecting the points plotted with straight lines as at *A*, Fig. 988. An empirical relationship between curve and plotted points may be used, as at *B*, when, in the opinion of the engineer, the curve should exactly follow some points, and go to one side of others. Consistency of observation is indicated at *C*, in which case the curve should closely follow a true theoretical curve.

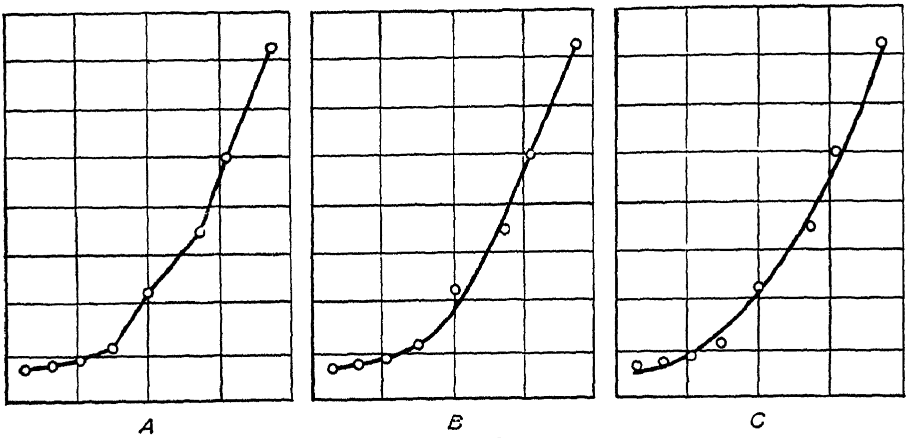


Fig. 988.—Methods of drawing curves.

455. Logarithmic Ruling.—A very important type of chart is that in which the divisions, instead of being equally spaced, are made proportional to the logarithms of the numbers at the margin instead of to the numbers themselves. When ruled logarithmically in one direction with equal spacing at right angles, it is called "semilogarithmic."

Logarithmic spacing may be done directly from the graduations on one of the scales of a slide rule. Log paper in various combinations of ruling is sold. It may be had in one, two, three or more cycles, or multiples of 10, also in part-cycle and split-cycle form. In using log paper, interpolations should be made logarithmically, not arithmetically as on rectangular coordinates, for arithmetical interpolation with coarse divisions might lead to considerable error.

456. The Semilogarithmic Chart.—This chart has equal spacing on one axis, usually the X-axis, and logarithmic spacing on the other axis. Owing to a property by virtue of which the slope of the curve at any point is an exact measure of the rate of increase or decrease in the data plotted, it is frequently called a "ratio chart." It is extremely useful in statistical work as it shows at a glance the rate at which a variable changes. Karsten aptly

calls it the "rate of change chart" as distinguished from the rectilinear or "amount of change chart." By the use of this chart it is possible to predict a trend, such as the future increase of a business, growth of population, etc.

In choosing between rectilinear ruling and semilog ruling the important point to consider is whether the chart is to represent *numerical* increases and decreases or *percentage* increases and decreases. In many cases it is desired to emphasize the percentage or rate change, not the numerical change; hence a semilog chart should be used.

An example of the use of the semilog chart is illustrated in Fig. 989. This curve was drawn from data compiled for *Automotive Industries* and furnished by R. B. Prescott, consulting statistician. The dash line shows

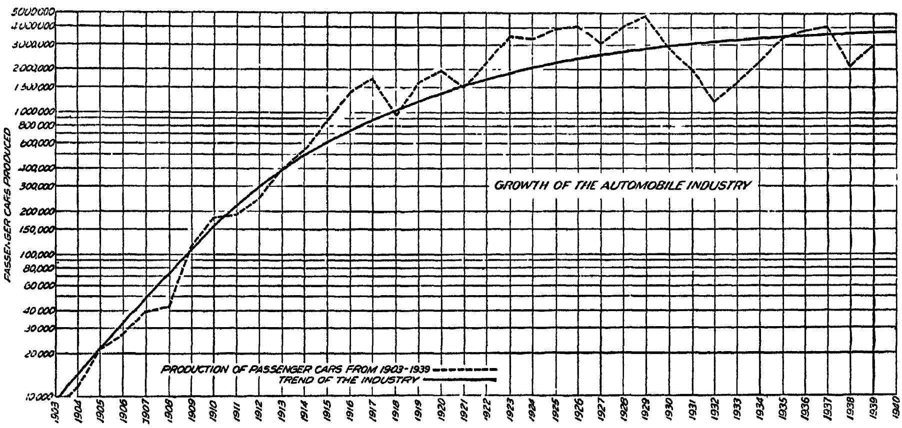


FIG. 989.—A curve on semilogarithmic paper.

the actual production by years, and the full line is the trend curve, the extension of which predicts future production.

457. The function of a chart is to reveal facts. It may be entirely misleading if a wrong choice of paper or coordinates is taken. The growth of an operation plotted on a rectilinear chart might, for example, entirely mislead an owner analyzing the trend of his business, while if plotted on a semilog chart it would give a true picture of conditions. Intentionally misleading charts have been used many times in advertising matter, the commonest form being the chart with a greatly exaggerated vertical scale.

458. Logarithmic charts with both abscissas and ordinates spaced logarithmically are used more for the solution of problems than for presenting facts. A property which distinguishes the logarithmic chart and accounts for its usefulness in so many cases is that the graphs of all algebraic equations representing multiplication, division, roots and powers are straight lines. If the equation $x^2y = 16$ were plotted on ordinary rectangular coordinates the resulting curve would be a hyperbola of the third degree with the x and y axes as asymptotes. By taking the logarithms of both sides of the given equation it becomes $2 \log x + \log y = \log 16$. The equation now has the

slope intercept form $y = mx + b$ and if so desired could be plotted on rectangular coordinates by substituting the logarithms of the variables. Obviously, it is easier to use logarithmic coordinates and plot the points directly than to take the logarithms of the variables and plot them on rectangular coordinates.

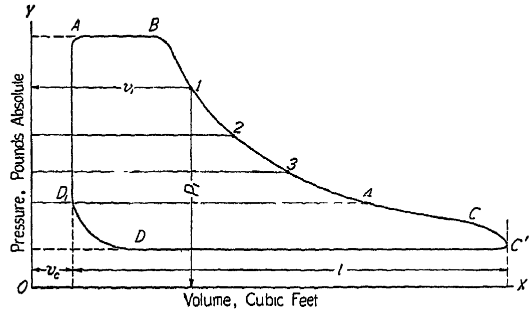


FIG. 990.—Indicator diagram.

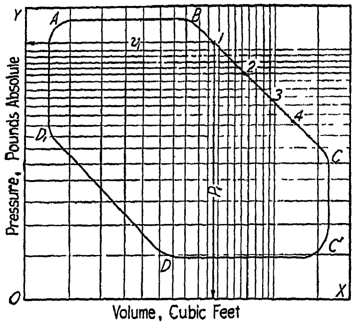


FIG. 991.—Indicator diagram on log paper.

A feature of the logarithmic chart which makes it valuable for the study of many problems is that the exponent in the equation may be determined by measuring the slope of the graph. An inspection of the foregoing equations will show that the slope m, as given by the slope intercept form, is -2. The value of this exponent may be determined by direct measurement of the slope, using a uniformly graduated scale.

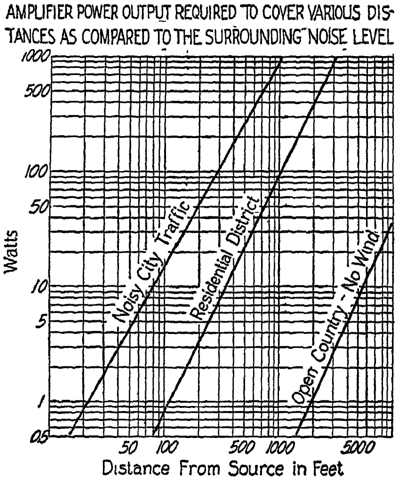


FIG. 992.—Multiple cycle ruling.

Figures 990 and 991 show an example of the use of a logarithmic chart in studying steam-engine performance. When the indicator card, Fig. 990, is plotted on log paper it takes the form shown in Fig. 991. The hyperbolas of a perfect card become straight lines, deviations from which indicate faults.

Figure 992 illustrates the use of multiple-cycle paper.

459. The Polar Chart.—The use of polar coordinate paper for representing intensity of illumination, intensity of heat, polar forms of curves, etc., is common. Figure 993 shows a candle-power distribution curve for an ordinary Mazda B lamp and Fig. 994 the curve for a certain type of reflector. The candle power in any given direction is determined by reading off the distance from the origin to the curve. Use of these curves enables the determination of the foot-candle intensity at any point.

460. The Trilinear Chart.—The trilinear chart, or "triaxial diagram" as it is sometimes called, affords a valuable means of studying the properties of chemical compounds consisting of three elements, alloys of three metals

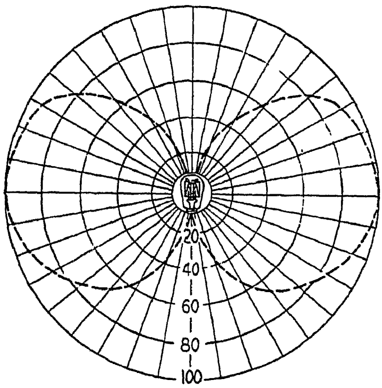


FIG. 993.—A polar chart.

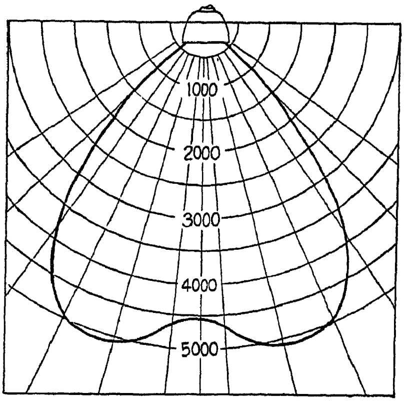


FIG. 994.—A polar chart.

or compounds and mixtures containing three variables. The chart has the form of an equilateral triangle the altitude of which represents 100 per cent of each of the three constituents. Figure 995, showing the tensile strength

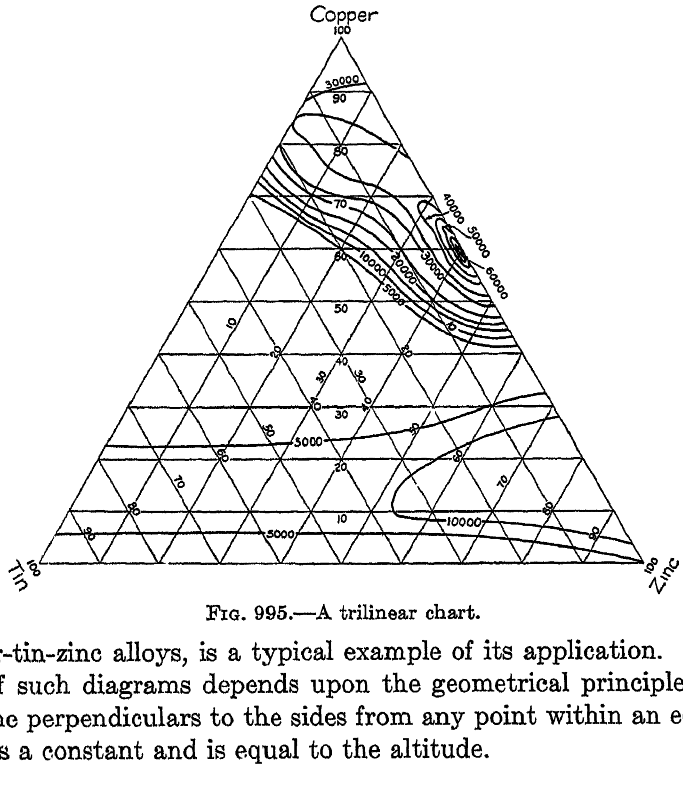


FIG. 995.—A trilinear chart.

of copper-tin-zinc alloys, is a typical example of its application. The usefulness of such diagrams depends upon the geometrical principle that the sum of the perpendiculars to the sides from any point within an equilateral triangle is a constant and is equal to the altitude.

461. Nomographs.—The simplest form of nomograph is the *alignment chart,* consisting of three parallel lines graduated and spaced in such a manner that a straight line passing through known values on two of the scales gives the proper corresponding value at its intersection with the third scale. After an alignment chart is constructed, it is one of the easiest and most accurate means for the solution of the equation for which it is designed. It is beyond our scope here to explain the mathematics underlying the construction of nomographs, as this chapter is only indicating and illustrating

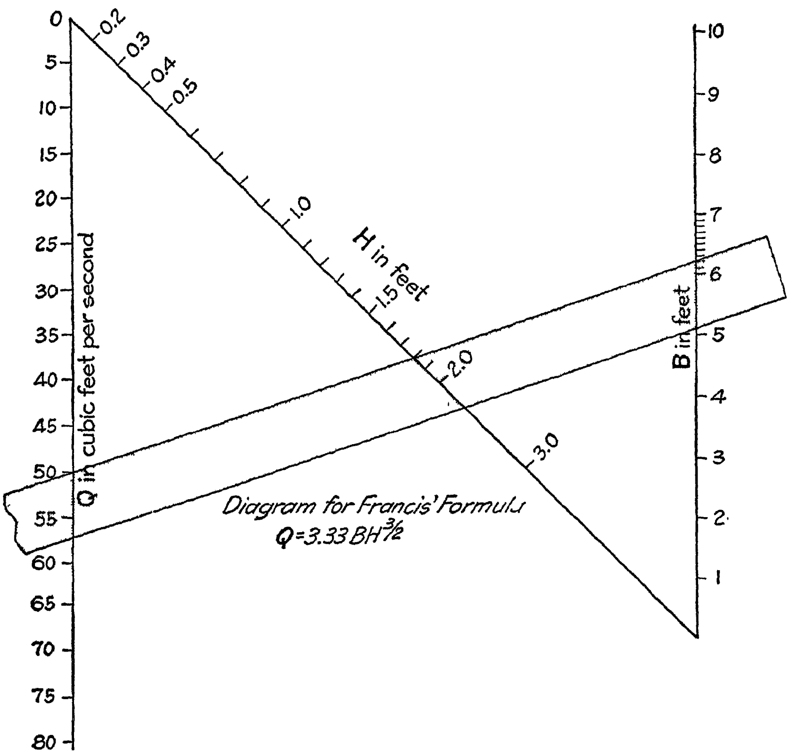


FIG. 996.—An alignment chart, or nomograph, of an equation. (*Redrawn from Hewes and Seward, "The Design of Diagrams for Engineering Formulas."*)

the various uses of graphic representation. The graduated lines in a nomograph need not be parallel, and any one or all of them may be either curved or straight, depending upon the equation represented. Figure 996 is one form of an alignment chart sometimes called, from its appearance, the "zigzag nomograph." The rectangular chart for the same equation is given for comparison in Fig. 997. The simplicity of the alignment chart is obvious.

462. Classification Charts, Route Charts and Flow Sheets.—The uses to which these three classes of charts may be put are widely different, but

their underlying principles are similar and they have thus been grouped together for convenience.

A classification chart, as illustrated in Fig. 998, is intended to show the subdivisions of a whole and the interrelation of its parts to each other.

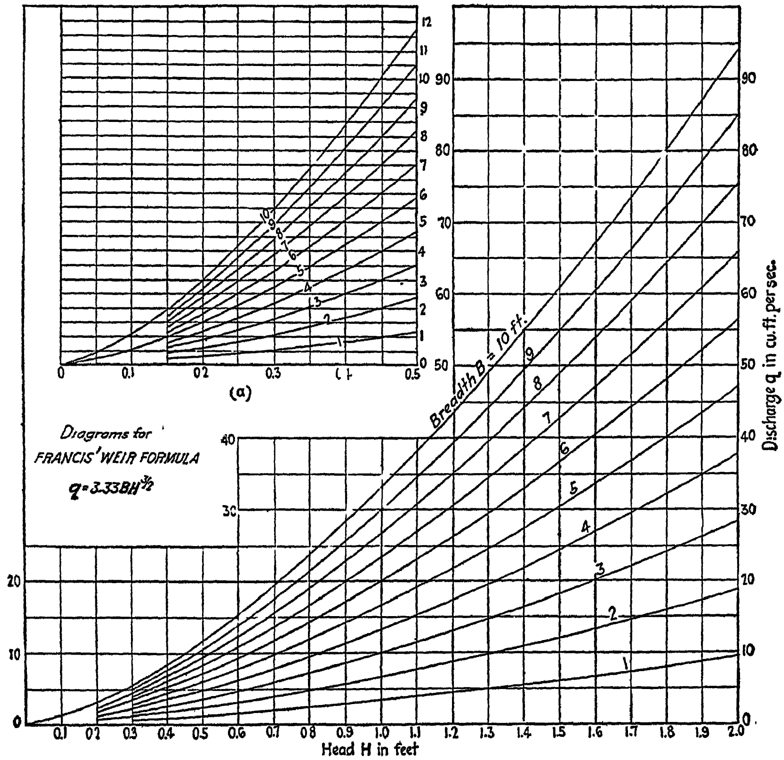


FIG. 997.—A rectilinear chart of an equation. (*Courtesy of Hewes and Seward, "The Design of Diagrams for Engineering Formulas."*)

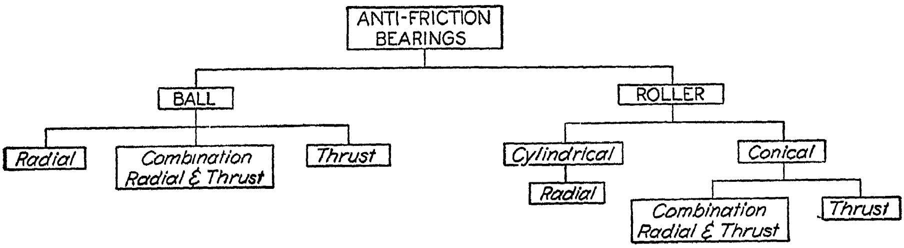


FIG. 998.—A classification chart.

Such a chart often takes the place of a written outline, since it gives a better visualization of the facts than words alone would convey. A common application is an organization chart of a corporation or business. It is customary to enclose the names of the divisions in rectangles, although circles or other shapes may be used. The rectangle has the advantage of

being more convenient for lettering, while the circle may be drawn more quickly and possesses a greater popular appeal. Often a combination of both is used.

The *route chart* is used mainly for the purpose of showing the various steps in a process, either of manufacturing or other business. The *flow sheet* given in Fig. 999 is an example of a route chart applied to a chemical process. Charts of this type show in a dynamic way facts which might require considerable study to comprehend from a written description. A different

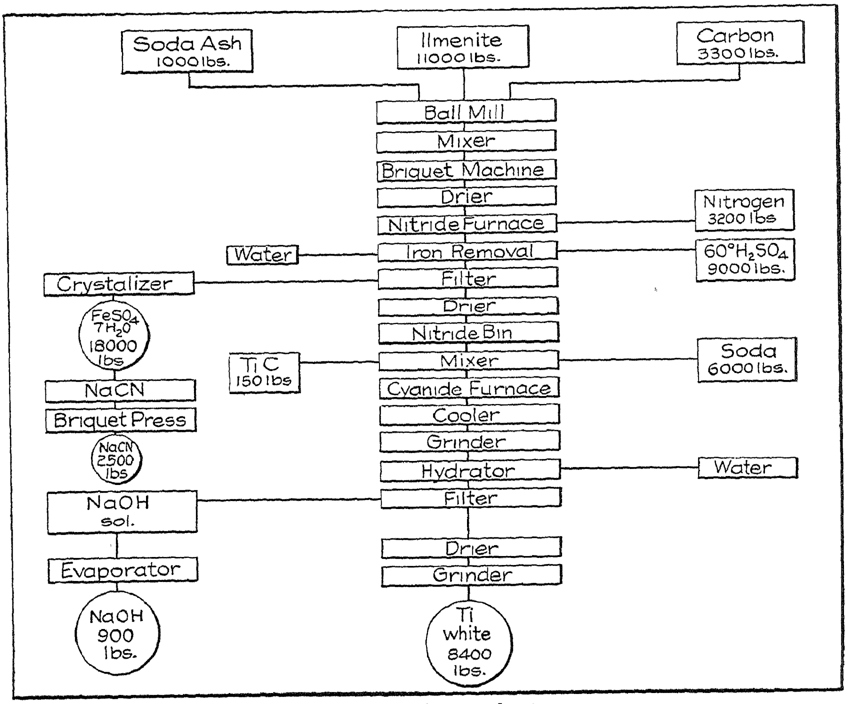


FIG. 999.—A flow sheet.

form of route chart is that of Fig. 415, showing the course of a drawing through the shops.

463. Popular Charts.—Engineers and draftsmen are frequently called upon to prepare charts and diagrams which will be understood by diversified and nontechnical readers. In many cases it is not advisable to present the facts by means of curves drawn on coordinate paper, although for the sake of greater effectiveness the resulting chart may suffer somewhat in accuracy. In preparing charts for popular use, particular care must be taken to make them so that the impression produced will be both quick and accurate. It is to be remembered that such charts are seldom studied critically but are taken in at a glance; hence the method of presentation requires the exercise of careful judgment and the application of a certain amount of psychology.

464. Bar Charts.—The bar chart is a very easily understood type for the nontechnical reader. One of its simplest forms is the *hundred per cent bar* for showing the relations of the constituents to a given total. Figure 1000 is an example of this form of chart. The different segments should be crosshatched, shaded or distinguished in some effective manner, the percentage represented placed on the diagram or directly opposite and the meaning of each segment clearly stated. These bars may be placed either vertically or horizontally, the vertical position giving an advantage for lettering, and the horizontal position an advantage in readability, as the eye judges horizontal distances readily.

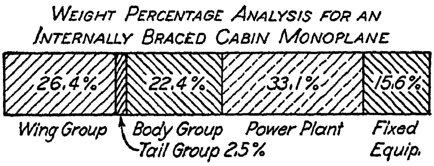


FIG. 1000.—A 100 per cent bar.

Figure 1001 is an example of a *multiple bar chart* in which the length of each bar is proportional to the magnitude of the quantity represented.

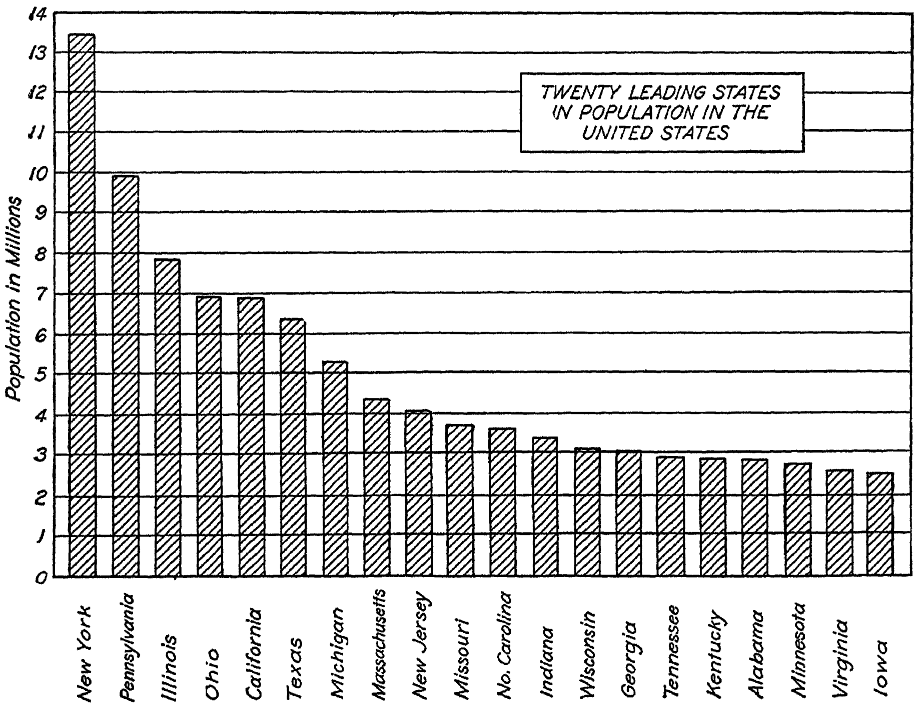


FIG. 1001.—Multiple bar chart.

Means should be provided for reading numerical values represented by the bars. If it is necessary to give the exact value represented by the individual bars, these values should not be lettered at the ends of the bars, since the apparent length would be increased. This type is made both horizontally, with the description at the base, and vertically. The vertical form is some-

times called the "pipe-organ chart." When vertical bars are drawn close together so as to touch along the sides the diagram is called a "staircase chart." This is made oftener as the "staircase curve," a line plotted on coordinate paper representing the profile of the tops of the bars.

A *compound bar chart* is made when it is desired to show two or more components in each bar. It is really a set of 100 per cent bars of different lengths set together either in pipe-organ or horizontal form.

465. Pie Charts.—The "pie diagram" or 100 per cent circle, Fig. 1002, is much inferior to the bar chart but is used constantly because of its insistent popular appeal. It is a simple form of chart and, with the exception of the lettering, is easily constructed. It may be regarded as a 100 per cent bar bent into circular form. The circumference of the circle is divided into 100 parts, and sectors are used to represent percentages of the total. To be effective, this diagram must be carefully lettered and the percentages marked on the sectors or at the circumference opposite the sectors. For contrast it is best to crosshatch or shade the individual sectors. If the original drawing is to be displayed, the sectors may be colored and the diagram supplied with a key showing the meaning of each color. In every case the percentage notation should be placed where it can be read without removing the eyes from the diagram.

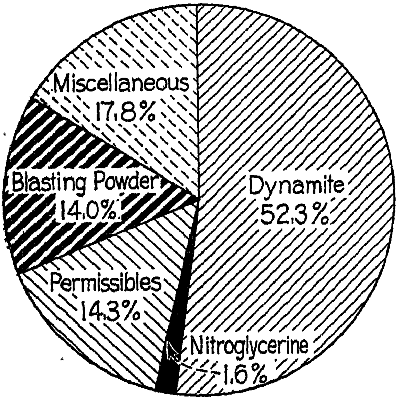


FIG. 1002.—A pie chart.

466. Area and Volume Diagrams.—The use of area and volume diagrams has been very common, although they are usually the most deceptive of the graphic methods of representation. Pictorial charts of this type were formerly much used for comparisons, such as of populations, standing armies, livestock and other products. It was customary to represent the data by human figures, whose heights were proportional to the numerical values, or by silhouettes of the animals or products concerned, whose heights or sometimes areas were proportional. Since volumes vary as the cubes of the linear dimensions, such charts are grossly misleading. For such comparisons bar charts or even pie diagrams should be used.

There are occasions when area diagrams offer the most logical and effective method of presentation, as in Fig. 1003. Such a chart may be regarded as a series of vertical 100 per cent bars placed side by side.

467. To Draw a Chart.—In drawing a coordinate chart the general order is (1) compute and assemble all data, (2) determine size and kind of chart best adapted and whether printed or plain paper should be used, (3) determine, from the limits of the data, the scales for abscissas and ordinates to

give the best effect to the resulting curve, (4) lay off the independent variable (often *time*) on the horizontal or X-axis, and the dependent variable on the vertical or Y-axis; (5) plot points from the data and pencil the curves, (6) ink the curve and (7) compose and letter title and coordinates.

When the chart is drawn on a printed form, to be blueprinted, the curve may be drawn on the reverse side of the paper, enabling erasures to be made without injuring the ruled surface.

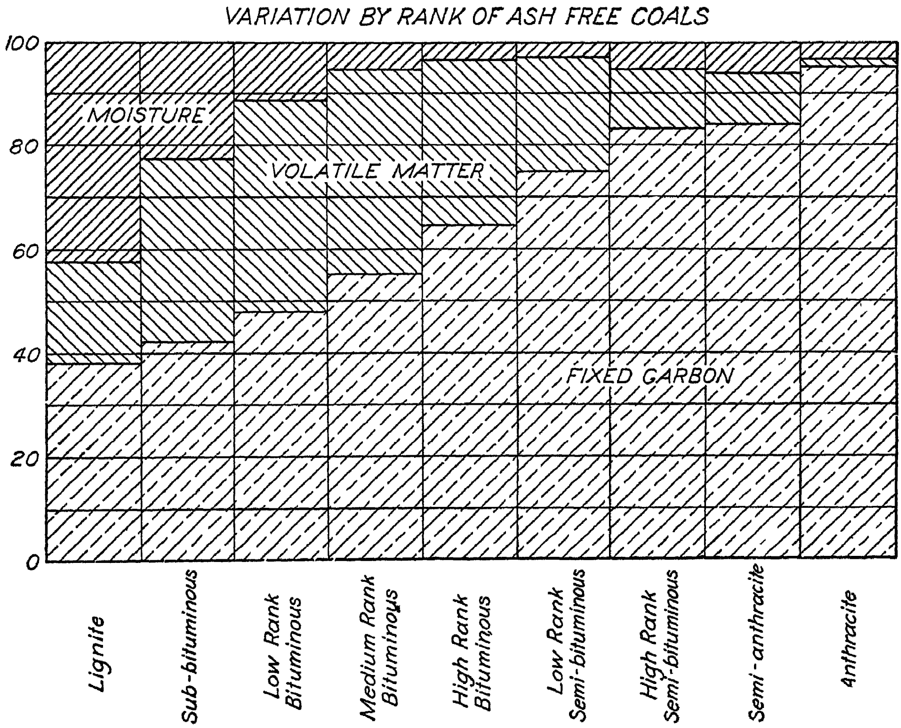


FIG. 1003.—An area diagram.

Green is becoming the standard color for printed forms. Blue will not print or photograph and red is trying on the eyes.

If the curve is for purposes of computation it should be drawn with a fine accurate line. If for demonstration it should be fairly heavy, for contrast and effect.

The Joint Committee on Standards for Graphic Presentation recommends the following rules:

Standards for Graphic Presentations

1. The general arrangement of a diagram should proceed from left to right.
2. Where possible, represent quantities by linear magnitude, as areas or volumes are likely to be misinterpreted.

3. For a curve the vertical scale, whenever practicable, should be so selected that the zero line will appear in the diagram.
4. If the zero line of the vertical scale will not normally appear in the curve diagram, the zero line should be shown by the use of a horizontal break in the diagram.
5. The zero lines of the scales for a curve should be sharply distinguished from the other coordinate lines.
6. For curves having a scale representing percentages, it is usually desirable to emphasize in some distinctive way the 100 per cent line or other line used as a basis of comparison.
7. When the scale of a diagram refers to dates, and the period represented is not a complete unit, it is better not to emphasize the first and last ordinates, since such a diagram does not represent the beginning and end of time.
8. When the curves are drawn on logarithmic coordinates, the limiting lines of the diagram should each be at some power of 10 on the logarithmic scale.
9. It is advisable not to show any more coordinate lines than necessary to guide the eye in reading the diagram.
10. The curve lines of a diagram should be sharply distinguished from the ruling.
11. In curves representing a series of observations, it is advisable, whenever possible, to indicate clearly on the diagram all the points representing the separate observations.
12. The horizontal scale for curves should usually read from left to right and the vertical scale from bottom to top.
13. Figures for the scale of a diagram should be placed at the left and at the bottom or along the respective axes.
14. It is often desirable to include in the diagram the numerical data or formula represented.
15. If numerical data are not included in the diagram, it is desirable to give the data in tabular form accompanying the diagram.
16. All lettering and all figures in a diagram should be placed so as to be easily read from the base as the bottom or from the right-hand edge of the diagram as the bottom.
17. The title of a diagram should be made as clear and complete as possible. Subtitles or descriptions should be added if necessary to ensure clearness.

468. Charts for Reproduction.—Charts for reproduction by the zinc-etching process should be carefully penciled to about twice the size of the required cut. See Drawing for Reproduction, paragraph 478. In inking, first ink circles around plotted points; second, ink the curves with strong lines. A border pen is useful for heavy lines, and a Payzant pen may be used to advantage, particularly with dotted lines. Third, ink the title box and all lettering; fourth, ink the coordinates with fine black lines, putting in only as many as are necessary for easy reading, and breaking them wherever they interfere with title or lettering or where they cross plotted points.

469. Charts for Display.—Large charts for demonstration purposes are sometimes required. These may be drawn on sheets 22″ × 28″ or 28″ × 44″ known as "printer's blanks." The quickest way to make them is with the

show-card colors and single-stroke sign writer's brushes. Large bar charts may be made with strips of black adhesive tape. Lettering may be done with the brush or with gummed letters.

PROBLEMS

470. The following problems are given as suggestive of various types for both technical and popular presentation.

1. During a certain chemical process the rise in temperature varied with the time as given in the following data:

Time	Temperature, °C.	Time	Temperature, °C.
0	0	7	136
1	33	8	139
2	66	9	142
3	93	10	143
4	110	11	144
5	123	12	155
6	131		

Using $8\frac{1}{2}'' \times 11''$ paper divided into inches and twentieths show graphically the relation between the time and the corresponding rise in temperature.

2. In a tension test of a machine-steel bar the following data were obtained:

Applied Load, Pounds per Square Inch	Elongation per Inch of Length
0	0
3,000	0.00011
5,000	0.00018
10,000	0.00033
15,000	0.00051
20,000	0.00067
25,000	0.00083
30,000	0.00099
35,000	0.00115
40,000	0.00134
42,000	0.00142

Plot the foregoing data on rectangular coordinates using the elongation as the independent variable and the applied load as the dependent variable.

3. In testing a small 1-kilowatt transformer for efficiency at various loads the following data were obtained:

Watts Delivered	Losses
948	73
728	62
458	53
252	49
000	47

Plot curves on rectangular coordinate paper showing the relation between percentage of load and efficiency, using watts delivered as the independent variable and remembering that efficiency = output ÷ (output + losses).

4. The following data were obtained from a test of an automobile engine:

Rpm	Length of run, minutes	Fuel per run, pounds	Brake horsepower
1,006	11.08	1 0	5.5
1,001	4.25	0.5	8.5
997	7.53	1.0	13.0
1,000	5 77	1.0	16.3
1,002	2.38	0.5	21.1

Plot curves on rectangular coordinate paper showing the relation between fuel used per brake horsepower-hour and brake horsepower developed. Show also the relation between thermal efficiency and brake horsepower developed assuming the heat value of the gasoline to be 19,000 British thermal units per pound.

5. During a certain year the consumption of bleaching powder by industries was as follows:

Industry	Tons
Pulp and paper	64,000
Textile	16,000
Water purification	9,000
Laundry	4,000
Miscellaneous	7,000

Show these facts by means of a 100 per cent bar, a pie diagram and a bar chart. After having drawn these three charts determine which one you would use if you were presenting the information to the president of a manufacturing company; to the general public; to a group of engineers.

6. Make a semilogarithmic chart showing the comparative rate of growth of the five largest American cities during the past 50 years. Data for this chart may be obtained from the U.S. Census Bureau Reports.

7. Make a compound bar chart showing the proportion of men and women students in your school in first, second, third and fourth years. Data from the registrar.

8. Make a multiple bar chart showing the minimum distances required to stop a modern automobile by an average driver having normal reflex. Distinguish between "thinking distance" and "braking distance." Source of data: Iowa Motor Vehicle department. Title: Speed and Stopping Distances.

Miles per hour	Feet per second	Thinking distance, feet	Braking distance, feet
20	29	22	18
30	44	33	40
40	59	44	71
50	74	55	111
60	88	66	160
70	103	77	218

9. Make a rectilinear chart showing the fluctuation of one active listed stock during the past month. The data for this may be obtained from the daily papers or from a stockbroker.

10. Draw a chart showing the growth of life insurance in this country in number of policies and in value, from 1900 to date. Data from *World Almanac.*

11. Put the data of Fig. 1002 into 100 per cent bar form.

12. Make an organization chart of (*a*) your city government, (*b*) the administration of your school, (*c*) a small manufacturing concern.

CHAPTER XXVIII

DUPLICATION AND DRAWING FOR REPRODUCTION

471. As has already been indicated, working drawings go to the shop as prints from the original drawings, which are carefully kept in the files for record. Several different processes for duplicating drawings are in use, with all of which the best results are obtained from tracings inked on tracing cloth. Sometimes, for economy, tracings are inked on paper. A large percentage of drawings are made in pencil on translucent paper or pencil cloth, and when the penciling is done skillfully, with uniform, opaque lines, very good blueprints can be made from them.

472. Tracing cloth is a fine-thread fabric sized and transparentized with a starch preparation. The smooth side is considered by the makers as the working side, but most draftsmen prefer to work on the dull side, which will take pencil marks. The cloth should be tacked down smoothly over the pencil drawing and its selvage torn off. To remove the traces of grease that sometimes prevent the flow of ink, it should then be dusted with chalk or prepared pounce (a blackboard eraser may be used) and rubbed off with a cloth.

473. Tracing.—To ensure good printing, the ink should be perfectly black and the ruling pens in good condition. Red ink should not be used unless it is desired to have some lines less conspicuous on the print. Blue ink will not print well. Sometimes, in maps, diagrams, etc., to avoid confusion of lines it is desirable to use colored inks on the tracing; in such cases, a little Chinese white added will render them opaque enough to print.

Occasionally, instead of section-lining sections they are indicated by rubbing a pencil tint over the surface on the dull side of the tracing cloth or by putting a wash of color on it. These tints will print on a blueprint in lighter blue than the background.

Ink lines may be removed from tracing cloth by rubbing with a pencil eraser, slipping a triangle under the tracing to give a harder surface. The rubbed surface should afterward be burnished with an ivory or bone burnisher or with the fingernail. In tracing a part that has been section-lined, a piece of white paper should be slipped under the cloth and the section lining done without reference to the section lines underneath.

Tracing cloth is very sensitive to atmospheric changes, often expanding over night so as to require restretching. If the complete tracing cannot be finished during the day, some views should be finished and no figure left with only part of its lines traced.

In making a large tracing it is well to cut off the required piece from the roll and lay it exposed, flat, for a short time before tacking it down.

Water will ruin a tracing on starch-coated cloth, and moist hands or arms should not come in contact with it. The habit should be formed of keeping the hands off drawings. It is a good plan, in both drawing and tracing on large sheets, to cut a mask of drawing paper to cover all but the view being worked on. Unfinished drawings should always be covered overnight.

Sometimes it is desired to add an extra view or a title to a print without putting it on the tracing. This may be done by drawing the desired additions on another piece of cloth of the same size as the original and printing the two tracings together.

Tracings may be cleaned of pencil marks and dirt by rubbing over with a cloth or waste dipped in benzine or carbon tetrachloride. To prevent smearing when using this method of cleaning, titles and border, if printed from type on the tracing cloth, should be printed in an ink not affected by benzine.

Soft cloths for penwipers may be made by washing the starch out of scrap tracing cloth.

The tracing is a "master drawing," and no one should ever be allowed to take it out of the office.

Pencil cloth is a transparentized fabric similar to tracing cloth except that one or both sides of its surface is prepared to take pencil, so that the original drawing may be made on it and prints made either from the pencil drawing or after it has been inked. Some of these newer cloths are moisture resistant, others are really waterproof. Pencil cloth is made for pencil drawings, and perfect blueprints can be made from drawings made on it with sharp hard pencils. Ink lines, however, do not adhere well and have a tendency to chip or rub off in cleaning.

474. Blueprinting.—The simplest and most generally used copying process is the blueprinting process, in which the prints are made by exposing a piece of sensitized paper and a tracing in close surface contact with each other to sunlight or electric light in a printing frame made for the purpose. This paper is a white stock free from sulphites, coated with a solution of citrate of iron and ammonia, and ferricyanide of potassium. On exposure to the light a chemical action takes place, which when fixed by washing in water gives a strong blue color. The parts protected from the light by the black lines of the tracing wash out, leaving the white paper. Blueprint paper is usually bought ready sensitized and may be had in different weights and different degrees of rapidity. When fresh it is of a yellowish green color, and an unexposed piece should wash out perfectly white. With age or exposure to light or air it turns to a darker gray-blue color and spoils altogether in a comparatively short time. In some emergency it may be necessary to prepare blueprint paper. The following formula will give a paper requiring about 3 minutes' exposure in bright sunlight.

1. Citrate of iron and ammonia (brown scales), 2 ounces; water, 8 ounces.
2. Red prussiate of potash, 1½ ounces; water, 8 ounces. Keep in separate bottles, away from the light. To prepare paper take equal parts of 1 and 2 and apply evenly to the paper with a sponge or camel-hair brush in subdued light.

475. To Make a Blueprint.—Lay the tracing in the frame with the inked side toward the glass and place the paper on it with its sensitized surface against the tracing. Lock up in the frame so that there is a perfect contact between paper and tracing. See that no corners are turned under. Expose to the sunlight or electric light. If a frame having a hinged back is used, Fig. 1004, one side may be opened for examination.

When the paper is taken from the frame it will be a bluish-gray color with the heavier lines lighter than the background, the lighter lines perhaps not being distinguishable. Put the print in a bath of running water, taking care that air bubbles do not collect on the surface. At the end of 5 minutes hang up to dry. An overexposed print may often be saved by prolonged washing. The blue color may be intensified and the white cleared by dipping the print for a moment into a bath containing a solution of potassium bichromate (1 to 2 ounces of crystals to a gallon of water) and rinsing thoroughly. This treatment will bring back an apparently hopelessly "burned" print. Sodium bichromate is a cheaper substitute sometimes used. Prints may be cleared successfully by dipping in a bath of hydrogen peroxide, 1 ounce to the gallon.

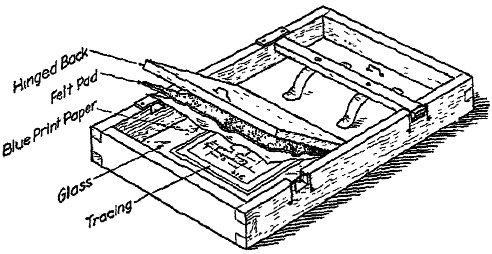


FIG. 1004.—A blueprint frame.

To be independent of the weather most concerns use electric printing machines, either *cylindrical*, in which a lamp is lowered automatically inside a glass cylinder about which the tracing and paper are placed, or *continuous*, in which the tracing and paper are fed through rolls, and in some machines printed, washed, "potashed" and dried in one operation. Figure 1005 shows a machine of this type.

Blueprint making is a recognized business, and blueprint concerns are found in every city. Many manufacturers and architects find it more satisfactory and economical to send their tracings out for printing than to maintain a blueprint room. Most of these concerns are equipped also for making photostats, black-and-white and other kinds of prints.

476. Changes are made on blueprints by writing or drawing with any alkaline solution, such as that of soda or potash, which bleaches the blue. Potassium oxalate is the best. A little gum arabic will prevent spreading. A tint may be given by adding a few drops of red or other colored ink to the solution. Chinese white, and special pencils, white or silver, are also used for white line changes on a blueprint.

A good blueprint may be made from a drawing in pencil or ink on thin paper, but with thick paper the light will get under the lines and destroy the sharpness. A print may be made from a drawing on Bristol or other heavy white paper by turning it with its ink side against the blueprint paper, although this reverses the print; or by first making a Van Dyke negative; or the drawing may be soaked in benzine and printed while wet. The benzine will evaporate and leave no trace.

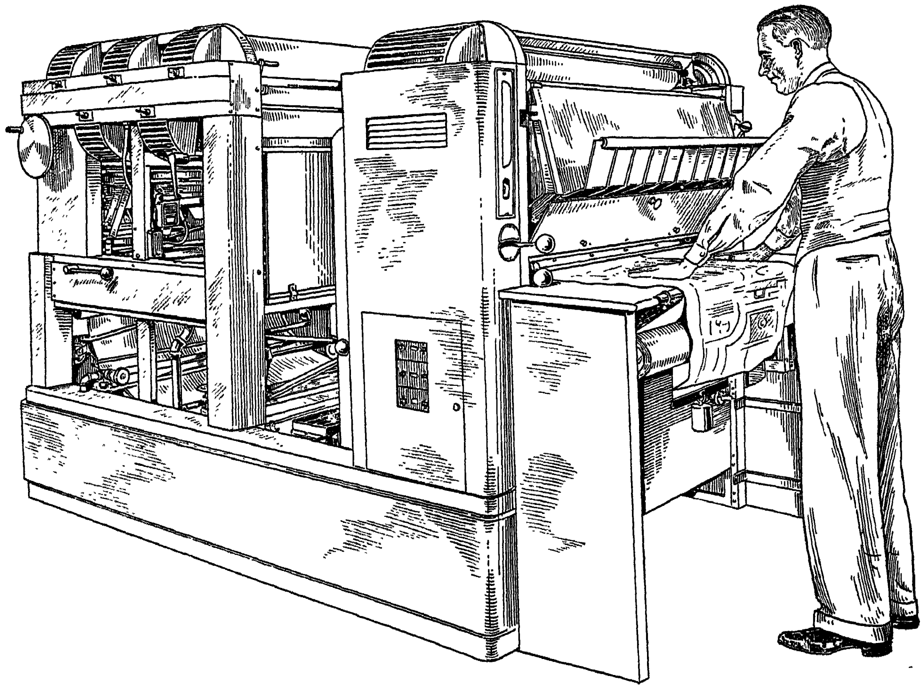


FIG. 1005.—An electric blueprinting machine with washing and drying equipment. (*Courtesy of The C. F. Pease Company, Chicago, Ill.*)

A clear blueprint can be made from a typewritten sheet which has been typed with a sheet of carbon paper back of it, so that it is printed on both sides. This method is extensively used in making bills of material, specification sheets, etc. Generally, $8\frac{1}{2}'' \times 11''$ paper is used.

In an emergency it is possible to make a fair print by holding tracing and paper to the sunlight against a windowpane.

Any white paper may be rendered sufficiently translucent to give a good blueprint by transparentizing with a solution of paraffin cut in benzine, or with a solution sold by drawing-materials dealers.

A blue-line print may be taken from a blueprint by fading the blue of the first print in weak ammonia water, washing thoroughly, then turning it red in a weak solution of tannic acid and washing again. Transparentizing at this stage will assist.

A number of small tracings may be fastened together at their edges and printed as a single sheet.

477. Other Printing Processes.—Van Dyke paper is a thin sensitized paper which turns dark brown when exposed to light and properly "fixed." It is fixed by first washing in water, then in hyposulphite of soda and again thoroughly in water. A reversed negative of a tracing may be made on it by exposing it to light with the inked side of the drawing next to the sensitized side of the paper; then this negative can be printed on blueprint paper, giving a positive print with blue lines on white.

B W paper, giving black lines on a white ground directly from the original tracing, is being used extensively when positive prints are desired.

Photostat prints are extensively used by large corporations. By this method a print with white lines on a dark background is made directly from any drawing or tracing, to any desired reduction or enlargement, through the use of a large specially designed camera. This print may be again photostated, giving a brown-line print with a white ground. This method is extremely useful to engineers for drawings to be included in reports, and for matching drawings of different scales which may have to be combined into one.

The Ozalid process, its name derived from the reversed spelling of diazo, is based on the chemical action of light-sensitive diazo compounds. It is a contact method of reproduction in which the exposure is made in either a regular blueprinting machine or an ozalid "whiteprint" machine, and the exposed print developed dry with ammonia vapors in a developing machine. Standard papers giving black, blue and maroon lines on a white ground are available. Dry developing has the distinct advantage of giving prints without distortion, and it also makes possible the use of transparent papers, cloth and foils to effect savings in drafting, as these transparent replicas can be changed by additions or erasures and prints made from them, without altering the original tracing.

Duplicating Tracings.—Tracings having all the qualities of ordinary inked ones are made photographically from pencil drawings by using a sensitized tracing cloth.

Lithoprinting.—When a number of copies of a drawing, fifty or more, are needed they may be reproduced by lithoprinting, a simplified form of photolithography, at comparatively small cost.

Copying methods, such as those of the mimeograph, ditto machine and other forms of the hectograph or gelatin pad are often used for small drawings.

478. Drawing for Reproduction.—By this term is meant the preparation of drawings for reproduction by one of the photomechanical processes used for making plates, or "cuts," as they are often called, for printing purposes. Such drawings are required in the preparation of illustrations for books and

periodicals, for catalogues or other advertising; and incidentally for patent-office drawings, which are reproduced by photolithography.

Line drawings are usually reproduced by the process known as "zinc etching," in which the drawing is photographed on a process plate, generally with some reduction, and the negative film reversed and printed so as to give a positive on a sensitized zinc plate (when a particularly fine result is desired, a copper plate is used); then this plate is etched with acid, leaving the lines in relief and giving, when mounted type-high on a wood base, a block which can be printed along with type in an ordinary printing press.

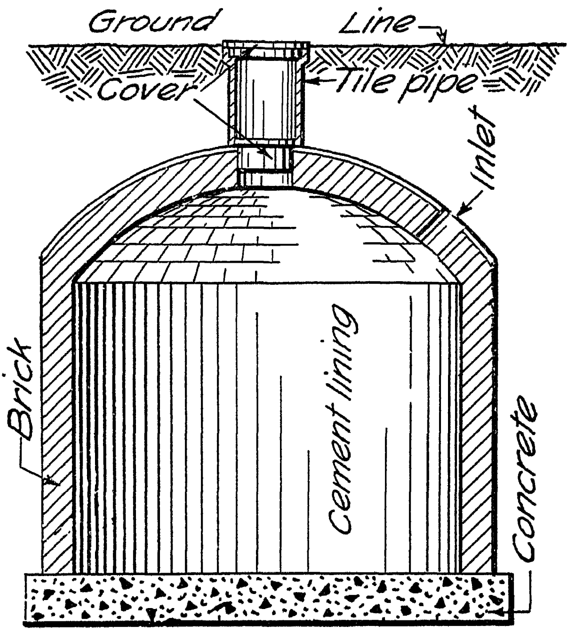


FIG. 1006.—Drawing for one-half reduction.

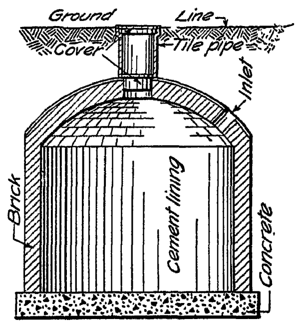


FIG. 1007.—One-half reduction.

Drawings for zinc etching should be made on smooth white paper or tracing cloth in black drawing ink, and preferably larger than the required reproduction. If it is desired to preserve the hand-drawn character of the original the reduction should be slight; but if a very smooth effect is wanted, the drawing may be as much as three or four times as large as the cut. The best general size is from one and one-half to two times the linear size of the cut. Figure 1006 illustrates the appearance of an original drawing, and Fig. 1007, the same drawing reduced one-half. Figure 1008 is another original which has been reduced two-thirds, Fig. 1009. The coarse appearance of these originals and the open shading should be noticed.

A reducing glass, a concave lens mounted like a reading glass, is sometimes used to aid in judging the appearance of a drawing on reduction. If

lines are drawn too close together the space between them will choke in the reproduction and mar the effect.

One very convenient thing not permissible in other work may be done on drawings for reproduction—any irregularities may be corrected by simply painting out with water-color white. If it is desired to shift a figure after

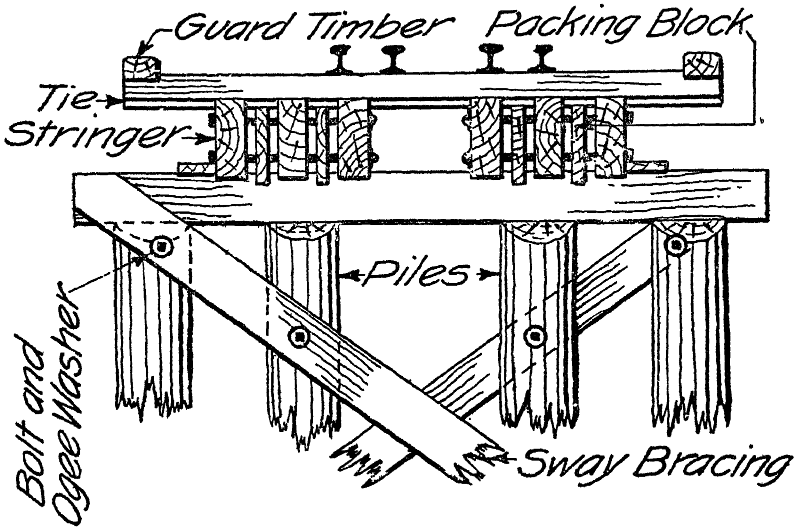


Fig. 1008.—Drawing for two-thirds reduction.

it has been inked it may be cut out and pasted on in the required position. The edges thus left will not trouble the engraver, as they will be tooled out when the etching is finished. Reference letters and numbers, notes and other lettering are often cut out of a sheet printed in type of proper size and pasted on the drawing.

Wash drawings and photographs are reproduced in a similar way on

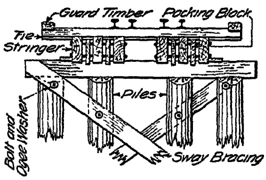


Fig. 1009.—Two-thirds reduction.

copper by what is known as the "half-tone process," in which the negative is made through a ruled "screen" placed in front of the plate, which breaks up the tints into a series of dots of varying size. Screens of different fineness are used for different kinds of paper, from the coarse-screen newspaper half tone of 80 to 100 lines to the inch, the ordinary commercial and magazine half tone of 133 lines, to the fine 150- and 175-line half tones for printing on very smooth coated paper.

Photographic prints for reproduction are often retouched and worked over, shadows being strengthened with water color, high lights accented with white and details brought out that would otherwise be lost. In catalogue illustrations of machinery, etc., objectionable backgrounds or other features can be removed entirely. Commercial retouchers use the airbrush as an aid

in this kind of work, spraying on color with it very rapidly and smoothly and securing results not possible in handwork.

So-called "phantom drawings" or "X-ray drawings" are made in this way, sometimes using a double-exposure negative as a basis.

The "Ben Day" film is another aid in commercial illustration that is used very extensively. Figure 16 is a simple example of its use.

Line illustrations are sometimes made by the "wax process," in which a blackened copper plate is covered with a very thin film of wax, on which a drawing may be photographed and its outline scratched through the wax by hand with different-sized gravers. The lettering is set up in type and

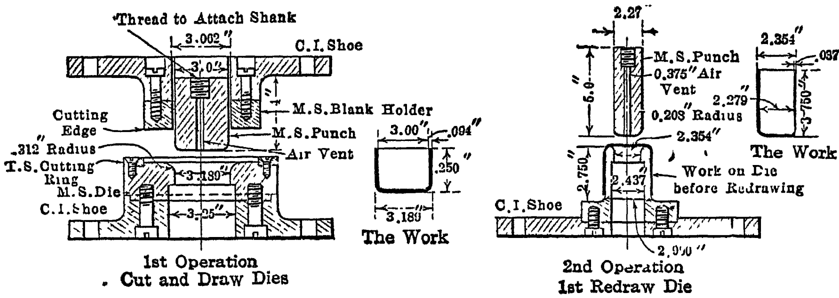


FIG. 1010.—A wax plate.

pressed into the wax; more wax is then piled up in the wider spaces between the lines and an electrotype taken. Drawings for this process need not be specially prepared, as the work may be done even from a pencil sketch or blueprint. Wax plates print very clean and sharp, and the type lettering gives them a finished appearance, but they lack the character of a drawing, are more expensive than zinc etching and often show mistakes due to the lack of familiarity of the engraver with the subject. Figure 1010 shows the characteristic appearance of a wax plate. Smaller maps are often made by this process.

Larger maps that formerly were engraved on stone for lithographic printing are now photolithographed on zinc and printed by the offset process, in which the thin sheet of zinc, carried on a cylinder, prints on a rubber blanket, which in turn prints on the paper.

CHAPTER XXIX

SHADE LINES AND LINE SHADING

479. Shade Lines.—The general practice on working drawings is to use a uniform bold full line for visible outlines. In some special kinds of work an effective appearance of relief and finish is given, and the legibility of the drawing increased, by using two weights of lines, light and heavy. This is used to advantage in technical illustrations, advertising matter, etc., where the definition of *shape* is the important feature. Shade lines are required on patent-office drawings and are used in a few shops on assembly drawings, but for ordinary shop drawings the advantage gained is much overbalanced by the increased cost.

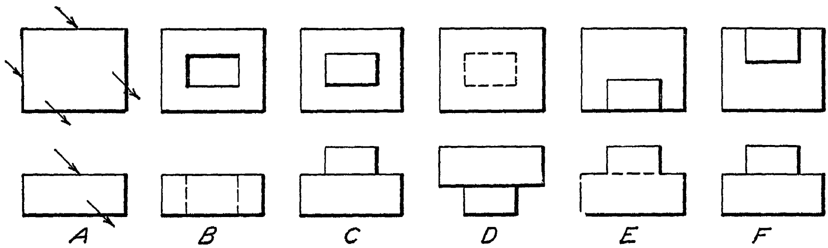


FIG. 1011.—Conventional shade lines.

Theoretically the shade-line system is based on the principle that the object is illuminated from one source of light at an infinite distance, the rays coming from the left in the direction of the body diagonal of a cube, so that the two projections of any ray each make an angle of 45° with the ground line. Part of the object is thus illuminated and part is in shade. A shade line is a line separating a light face from a dark face. The strict application of this theory involves some trouble, and it is not followed out in practice, but the one simple rule of shading the lower and right-hand lines of all views is observed, Fig. 1011. The light lines should be comparatively fine and the shade lines about three times as wide. The width of the shade line is added outside the outline of the view.

Figure 1012 shows two pieces in combination. At *A* the faces of the parts 1 and 2 are in the same plane; the line of the joint is, consequently, a light line. At *B* and *C* the faces are not in the same plane. Hidden lines are never shaded.

In inking a shade-line drawing it is important to follow the order of inking carefully. Ink (1) light arcs, (2) light to heavy arcs, (3) heavy arcs, (4) light lines and (5) heavy lines.

A circle may be shaded by shifting the center on a 45° line toward the lower right-hand corner an amount equal to the thickness of the shade line and drawing another semicircular arc with the same radius, Fig. 1013; or it

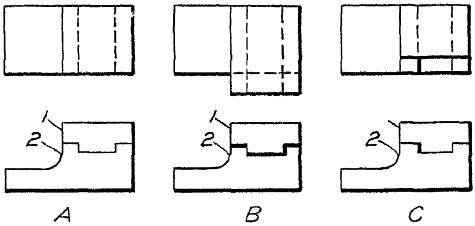


FIG. 1012.—Shading two pieces in combination.

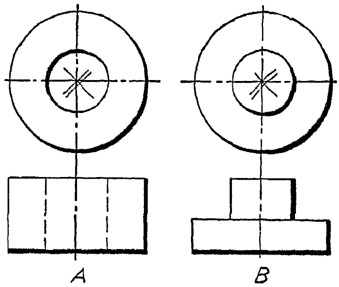


FIG. 1013.—Shifting the center.

may be done much more quickly, particularly with small circles, after the knack has been acquired, by keeping the needle in the center after drawing the circle and gradually springing the needle-point leg out and back while going over the half to be shaded, pressing with the middle finger in the position shown in Fig. 1014. Never shade a circle arc so that it appears heavier than the shaded straight lines.

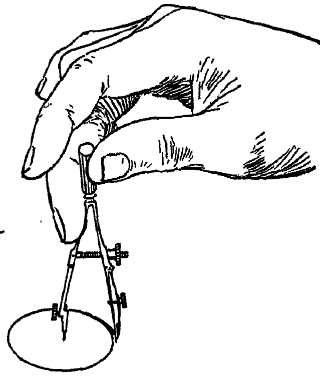


FIG. 1014.—Springing the point.

480. Shade lines in isometric drawing have no value so far as aiding in the reading is concerned, but they may by their contrast add some attractiveness to the appearance. Assuming the light to come from the left in the direction of the body diagonal of the isometric cube, and disregarding shadows, shade lines separating light from dark faces would appear as at B in Fig. 1015. Another method, popular among patent draftsmen and others using this kind of drawing for illustration, is to bring out the nearest corners with heavy lines, as at C.

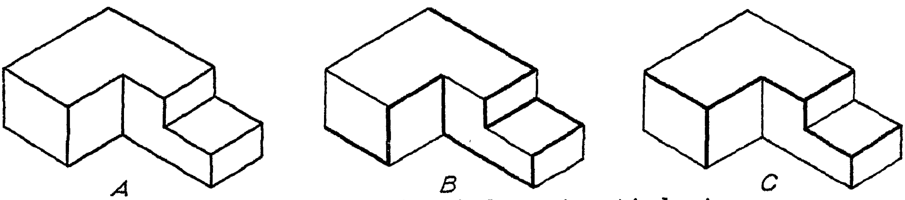


FIG. 1015.—Two methods of shading an isometric drawing.

481. Line Shading.—Line shading is a method of representing the effect of light and shade by ruled lines. The art of line shading is an accomplishment not usual among ordinary draftsmen as it is not used on

working drawings, and the draftsman engaged in that work does not have occasion to apply it. It is used on display drawings, illustrations, patent-office drawings and the like and is worthy of study if one is interested in this class of finished work.

To execute line shading rapidly and effectively requires continued practice, some artistic ability and, as much as anything else, good judgment in knowing when to stop. Often the simple shading of a shaft or other round member will add greatly to the effectiveness of a drawing and may even save making another view; or a few lines of "surface shading" on a flat surface will show its position and character. The pen must be in perfect condition, with its screw working very freely.

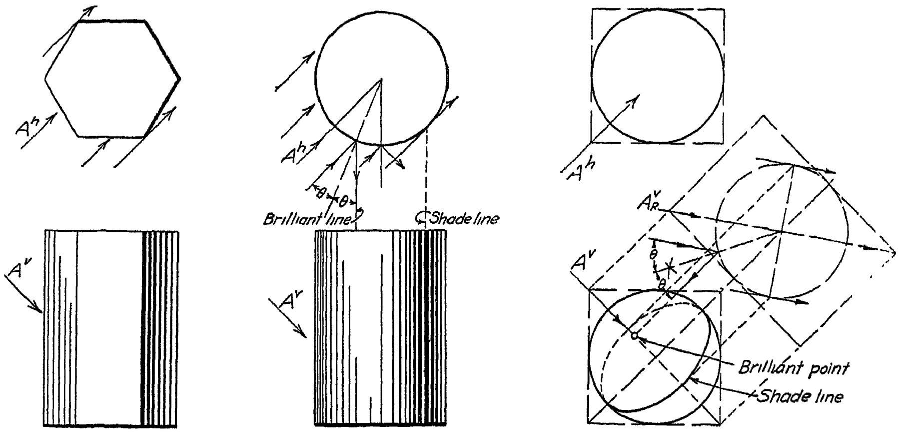


FIG. 1016. FIG. 1017. FIG. 1018.

FIGS. 1016, 1017, and 1018.—The theory of line shading.

482. Theory of Line Shading.—The theoretical direction of the light is, as already mentioned, in the direction of the body diagonal of a cube whose faces are parallel to the planes of projection. Thus the two projections of a ray of light would be as A^h and A^v, Fig. 1016, and two visible faces of the hexagonal prism would be illuminated, while one is in shade. It is immediately observed that the theoretical shade lines differ from the conventional ones as used in the preceding discussion. The figure illustrates the rule that *an inclined illuminated surface is lightest nearest the eye and an inclined surface in shade is darkest nearest the eye.*

A cylinder would be illuminated as in Fig. 1017. Theoretically the darkest place is at the tangent or "shade line" and lightest part at the "brilliant line" where the light is reflected directly to the eye. Cylinders shaded according to this theory are the most effective, but often in practice the dark side is carried out to the edge, and in small cylinders the light side is left unshaded.

A method of finding the brilliant point and shade line of a sphere is shown in Fig. 1018. A right auxiliary view of the sphere and circumscribing

cube is taken on a plane containing the body diagonal of the cube, and the angle between the auxiliary view of the ray of light and the auxiliary view of the center line to the eye bisected, giving the brilliant point. Tangents

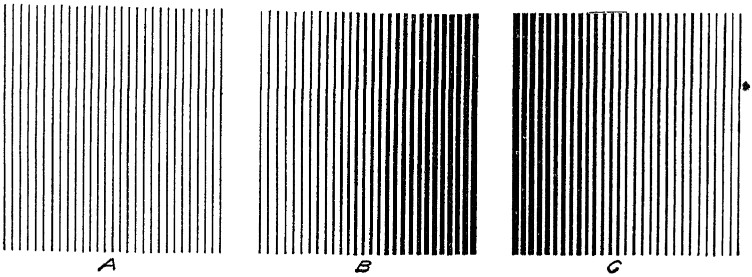


FIG. 1019.—Flat and graded tints.

to the auxiliary view of the sphere parallel to the auxiliary view of a ray of light locate the shade line.

483. Practice.—Three preliminary exercises in flat and graded tints are given in Fig. 1019. In these the pitch, or distance from center to center

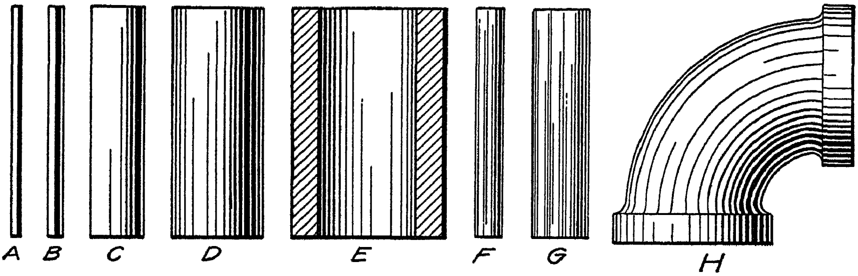


FIG. 1020.—Cylinder shading.

of lines, is equal. In wide-graded tints, as B and C, the setting of the pen is not changed for every line, but several lines are drawn, then the pen is changed, and several more drawn.

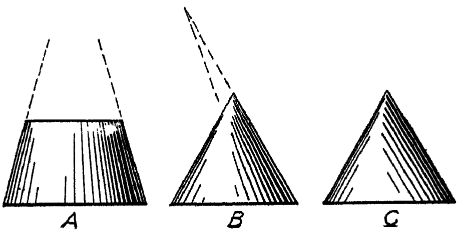


FIG. 1021.—Cone shading.

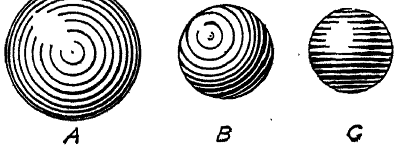


FIG. 1022.—Sphere shading.

Figure 1020 is a row of cylinders of different sizes. The effect of polish is given by leaving several brilliant lines, as might occur if the light came in through several windows. A conical surface may be shaded by driving a fine needle at the vertex and swinging a triangle about it as in A, Fig. 1021. To avoid a blot at the vertex of a complete cone the needle may be driven

on the extension of the side as in *B* or the lines may be drawn parallel to the sides as in *C*.

It is in the attempt to represent double-curved surfaces that the line shader meets his principal troubles. The brilliant line becomes a brilliant point and the tangent shade line a curve, and to represent the gradation between them by mechanical lines is a difficult task.

Three methods of shading a sphere are shown in Fig. 1022. The first one, *A*, is the commonest. Concentric circles are drawn from the center with varying pitch and shaded on the lower side by springing the point of the compasses. At *B* the brilliant point, usually "guessed in," is used as a

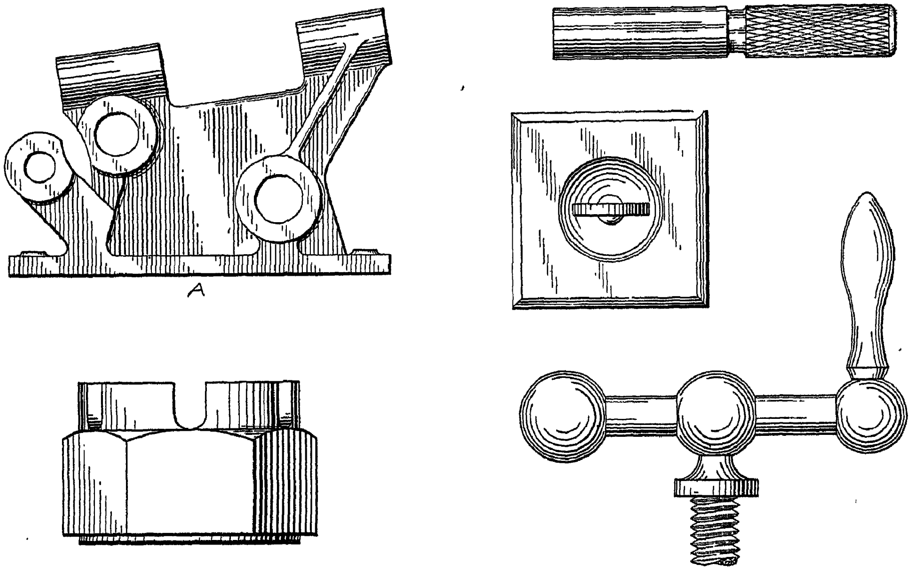


Fig. 1023.—Applications of line shading.

center. At *C*, the "woodcut" method, the taper on the horizontal lines is made by starting with the pen out of the perpendicular plane and turning the handle up as the line progresses. Applications of line shading on flat and curved surfaces are shown in Fig. 1023.

484. Patent-office Drawings.—In an application for letters patent on an invention or discovery a written description, called the "specification," and, in case of a machine, manufactured article or device for making it, a drawing, showing every feature of the invention, are required. If it is an improvement the drawing must show the invention separately, and in another view a part of the old structure with the invention attached. A high standard of execution and conformity to the rules of the Patent Office must be observed. A pamphlet called the *Rules of Practice*, giving full information and rules governing Patent-office procedure in applying for a patent, may be had by addressing the *Commissioner of Patents, Washington, D.C.*

The drawings are made on smooth white paper of a thickness corresponding to two-sheet or three-sheet Bristol board. The sheets must be exactly 10″ × 15″, with a border line 1″ from the edges. Sheets with border and lettering printed, as Fig. 1024, are sold by the dealers, but their use is not required. A space not less than 1¼″ inside the top border must be left blank for the printed title added by the Patent Office. Drawings must be made in India ink and drawn for a reproduction to reduced scale. As many sheets as are necessary may be used. In the case of large views any sheet may be turned on its side so that the heading is at the right and

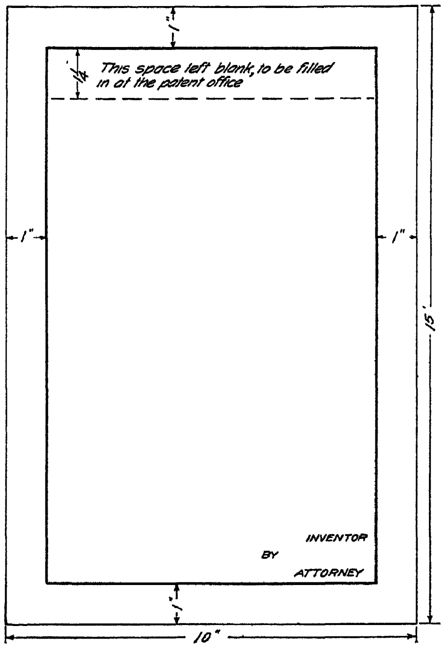


FIG. 1024.—Blank for a patent drawing.

the signatures at the left, but all views on the same sheet must stand in the same direction.

Patent-office drawings are not working drawings. They are descriptive and pictorial rather than structural; hence they will have no center lines, dimension lines, figured dimensions, notes or names of views. The scale chosen should be large enough to show the mechanism without crowding the views. Unessential details or shapes need not be represented with constructional accuracy, and parts need not be drawn strictly to scale. For example, the section of a thin sheet of metal drawn to scale might be a very thin single line, but it should be drawn with a double line and section-lined.

Section lining must not be too fine. One-twentieth of an inch pitch is a good limit. Solid black should not be used except to represent insulation or rubber. Shade lines are always added, except in special cases where they

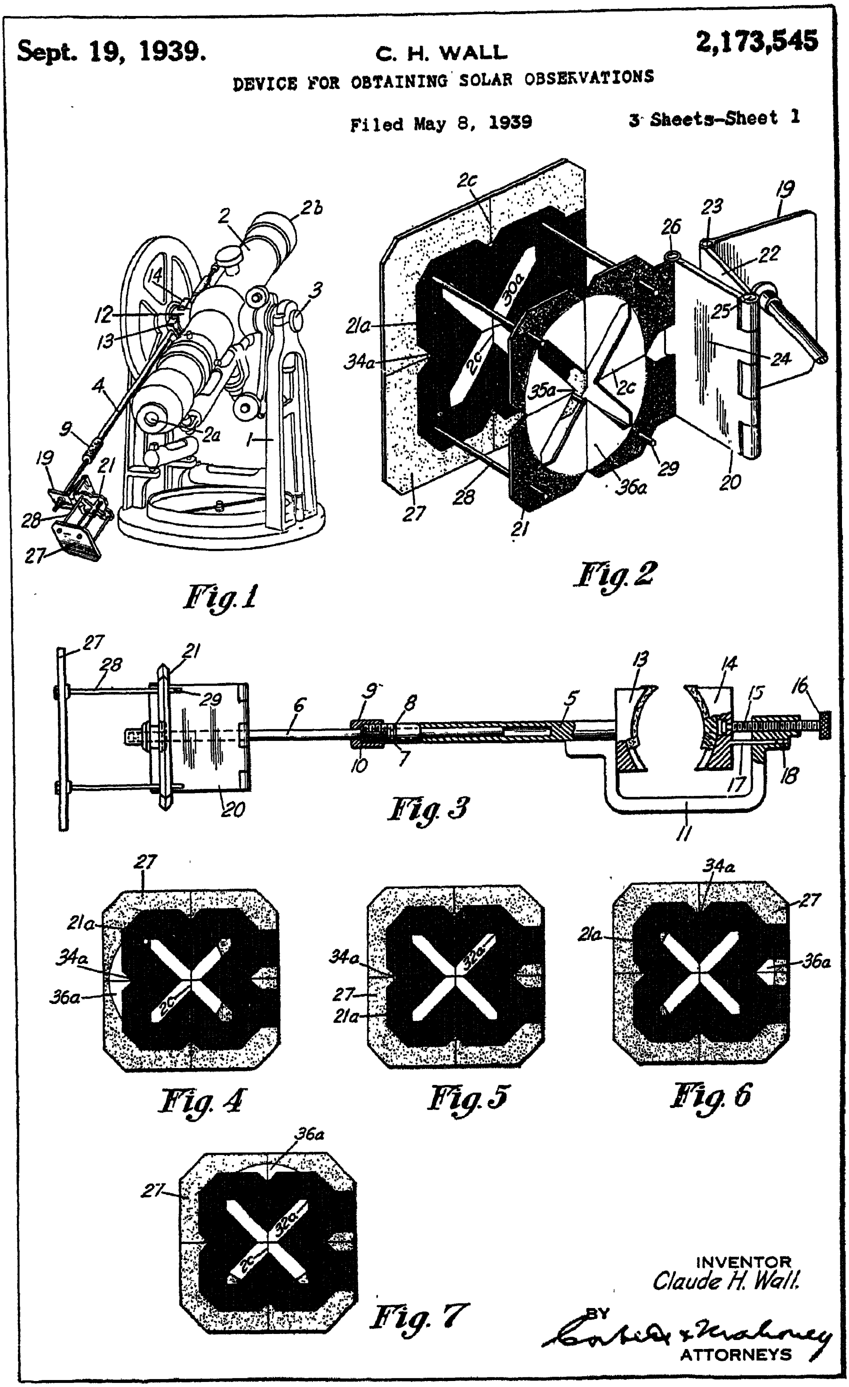


FIG. 1025.—A patent office drawing (reduced one-half).

might confuse or obscure instead of aid in the reading. Surface shading by line shading is used whenever it will aid legibility, but it should not be thrown in indiscriminately or lavishly, simply to please the client.

Gears and toothed wheels must have all their teeth shown, and the same is true of chains, sprockets, etc., but screw threads may be represented by the conventional symbols. The *Rules of Practice* gives a chart of electrical symbols, symbols for colors, etc., which should be followed.

The drawings may be made in orthographic, axonometric, oblique or perspective. The pictorial system is used extensively, for either all or part of the views. The examiner is, of course, expert in reading drawings, but the client, and sometimes the attorney, may not be, and the drawing should be clear to them. In checking the drawing for completeness it should be remembered that in case of litigation it may be an important exhibit in the courts. Only in rare cases is a model of an invention required by the Patent Office.

The views are lettered "Fig. 1," "Fig. 2," etc., and the parts designated by reference numbers through which the invention is described in the specification. One view, generally "Fig. 1," is made as a comprehensive view that may be used in the *Official Gazette* as an illustration to accompany the "claims."

The inventor signs the drawing in the lower right-hand corner. In case an attorney prepares the application and drawing, the attorney writes or letters the name of the inventor, signing his own name underneath as attorney.

To avoid making tack holes in the paper it should be held to the board by drafting tape or by the heads of the thumbtacks only.

The requirements for drawings for foreign patents vary in different countries, most countries requiring drawings and several tracings of each sheet.

Figure 1025 is an example of a patent-office drawing, reduced to one-half size.

CHAPTER XXX

NOTES ON COMMERCIAL PRACTICE

485. There are many items of practical information of value to the student and draftsman which are not included in the ordinary course in drawing but are learned through experience. A few miscellaneous points are given here as suggestions of kinds of information which are worth collecting and preserving in notebook form.

486. Stretching Paper.—If a drawing is to be tinted the paper should be stretched on the board. First, dampen it on both sides until limp, either with a sponge or under the faucet, then lay it on the drawing board face down, take up the excess water from the edges with a blotter, brush a strip of glue or paste about ½ inch wide around the edge, turn the paper over and rub its edges down on the board until set and allow to dry horizontally.

Drawings or maps on which much work is to be done, even though not to be tinted, may be made advantageously on stretched paper; but Bristol or calendered paper should not be stretched.

487. Tinting is done with washes made with water colors. The drawing may be inked (with waterproof ink) either before or preferably after tinting. The drawing should be cleaned and the unnecessary pencil marks removed with a very soft rubber, the tint being mixed in a saucer and applied with a camel-hair or sable brush. Incline the board and flow the color with horizontal strokes, leading the pool of color down over the surface, taking up the surplus at the bottom by wiping the brush out quickly and picking up with it the excess color. Stir the color each time the brush is dipped into the saucer. Tints should be made in light washes, depth of color being obtained if necessary by repeating the wash. To get an even color it is well to go over the surface first with a wash of clear water. Diluted colored inks may be used for washes instead of water color.

488. Mounting Tracing Paper.—Tracings on paper are mounted for display on white mounts, by either "tipping" or "floating." To tip a drawing, brush a narrow strip of glue or paste around the under edge, dampen the right side of the drawing by stroking with a sponge very lightly moistened and stretch the paper gently with the thumbs on opposite edges, working from the middle of the sides toward the corners.

To float a drawing make a *very thin* paste and brush a light coat over the entire surface of the mount, lay the tracing paper in position and stretch into contact with the board as in tipping. If air bubbles occur, force them out by rubbing from the center of the drawing outwardly, laying a piece of clean paper over the drawing to protect it.

489. Mounting on Cloth.—As a protection to maps and drawings requiring much handling it is advisable to mount them on cloth. The method to be used depends largely upon the weight and quality of the material to be mounted. A method suitable for one case might fail in another, but by having a general idea of the requirements it is possible to vary the method to suit the case. There are two methods used; hot mounting and cold mounting. The adhesives used are photo or library paste and liquid glue. The commercial products of each are so easily obtained that a formula for their preparation is unnecessary, and the ones to be used are largely a matter of choice and availability.

Hot mounting is the more satisfactory for average work because of the saving in time. The mounting cloth is usually a first grade of white light-weight sheeting. For small work, dust-colored dress lining is well suited. This is stretched tightly and tacked down over a table which has been previously covered with cloth. The paste is prepared by heating with a small amount of water until the solution becomes clear. With a broad flat brush cover the back of the print quickly with paste, working from the center toward the edges. Allow a moment for uniform expansion, then place face up on the cloth. Have iron hot but not enough to scorch, work quickly with rotary motion and iron print from center out until edges are stuck. Remove tacks and raise from table to release steam. Iron until dry. Never iron on the back, as the steam formed will cause blisters. Keep the iron well paraffined and a good gloss will be produced on the print. Liquid glue diluted and heated will work quite as well, but the sheet will not be so flexible and will break if folded too often.

Cold paste may be used instead of hot and is quite satisfactory. The method is practically the same except that a photographic print roller is substituted for the hot iron, and the print is allowed to become thoroughly dry before the tacks are removed.

Mounting Thin Paper.—The cloth is tacked down in the same way as for hot or cold mounting except that several thicknesses of newspaper are placed directly under the cloth. The hot paste is applied directly to the cloth until the cloth is thoroughly filled with paste. The print to be mounted is rolled, face in, from each end toward the center, leaving an equal amount of paper in each roll. With one roll in each hand place the print in the center of the pasted area, allowing only a few inches to unroll. Iron quickly as for hot mounting, unrolling the print as the ironing proceeds.

Another successful method consists in rolling the print to be mounted, face in, on a roll of detail paper. Hot paste is applied, beginning at one end, and the print rolled off on the cloth and followed up as fast as unrolled by a hot iron. It is inadvisable to apply paste to thin paper, unless supported as above, for it curls up so rapidly that it becomes unmanageable and results in the loss of the print.

490. Methods of Copying Drawings—Pricking.—Drawings are often copied on opaque paper by laying the drawing over the paper and pricking through with a needle point, turning the upper sheet back frequently and connecting the points. Prickers may be purchased or may be made easily by forcing a fine needle into a softwood handle. They may be used to advantage also in accurate drawing, in transferring measurements from scale to paper.

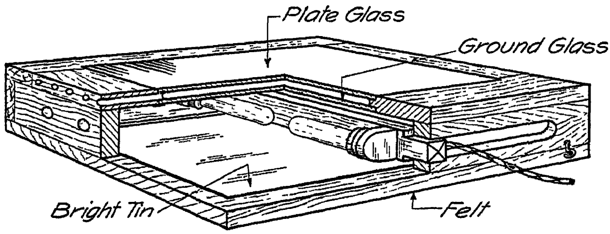


FIG. 1026.—A glass drawing board.

491. Transfer by Rubbing.—This method, known as *frotté,* is very useful, particularly in architectural drawing, in transferring any kind of sketch or design to the paper on which it is to be rendered.

The original is made on any paper and may be worked over, changed and marked up until the design is satisfactory. Lay a piece of tracing paper over the original and trace the outline carefully. Turn the tracing over and retrace the outline just as carefully on the other side, using a medium soft

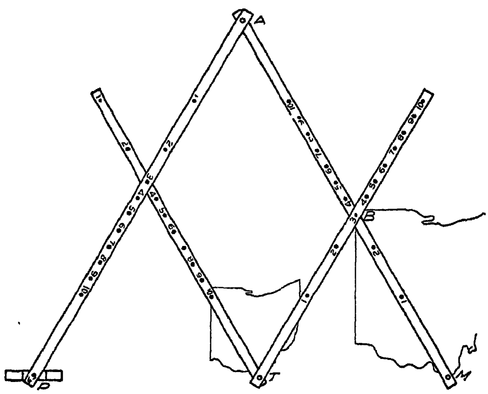


FIG. 1027.—A pantograph.

pencil with a *sharp* point. Turn back to first position and tack down smoothly over the paper on which the drawing is to be made, registering the tracing to proper position by center or reference lines on both tracing and drawing. Now transfer the drawing by rubbing the tracing with the rounded edge of a knife handle or other instrument (a smooth-edged coin held between thumb and forefinger and scraped back and forth is commonly

used), holding a small piece of tracing cloth with smooth side up between the rubbing instrument and the paper, to protect the paper. Do not rub too hard and be sure that neither the cloth nor the paper moves while rubbing. Transfers in ink instead of pencil, useful on wash drawings, may be made by tracing with *encre à poncer*, a rubbing ink made for this purpose.

If the drawing is symmetrical about any axis the reversed tracing need not be made, as the rubbing can be done from the first tracing by reversing it about the axis of symmetry.

Several rubbings can be made from one tracing, and when the same figure or detail must be repeated several times on a drawing, much time can be saved by drawing it on tracing paper and rubbing it in the several positions.

A very fine transfer of small details may be made by the engraver's method of tracing on a thin sheet of gelatin or celluloid, scratching the outline lightly with a sharp point, and rubbing colored crayon into the lines.

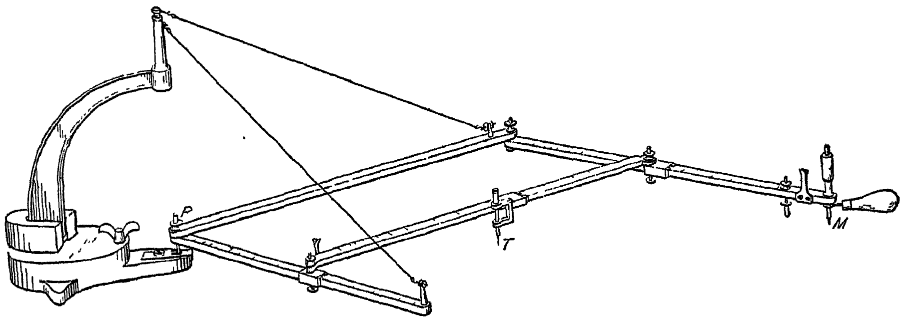


Fig. 1028.—A suspended pantograph.

492. Glass Drawing Board.—Drawing tables with glass tops and with lights in reflecting boxes underneath are successful devices for copying drawings on opaque paper. A portable design is shown in Fig. 1026. Drawings even in pencil may be copied readily on the heaviest paper or Bristol board by the use of a transparent drawing board.

493. Proportional Methods—The Pantograph.—The principle of the pantograph, used for reducing or enlarging drawings in any proportion, is well known. The instrument consists essentially of four bars, which for any setting must form a parallelogram and have the pivot, tracing point and marking point in a straight line; and any arrangement of four arms conforming to this requirement will work in true proportion. With reference to Fig. 1027, the scale of enlargement is PM to PT or AM to AB. For corresponding reduction the tracing point and marking point are interchanged. The inexpensive wooden form of Fig. 1027 is sufficiently accurate for ordinary outlining. A suspended pantograph with metal arms, for accurate engineering work, is shown in Fig. 1028.

Drawings may be copied to reduced or enlarged scale by using the proportional dividers, illustrated in Fig. 1029. The divisions marked "lines" are linear proportions, those marked "circles" give the setting for dividing a circle into a desired number of equal parts when the large end is opened to the diameter of the circle.

The well-known method of *proportional squares* is often used for reduction or enlargement. The drawing to be copied is ruled in squares of convenient size, or, if it is undesirable to mark on the drawing, a sheet of ruled tracing cloth or celluloid is laid over it, and the copy made freehand on the paper, which has been ruled in corresponding squares, larger or smaller, Fig. 1030.

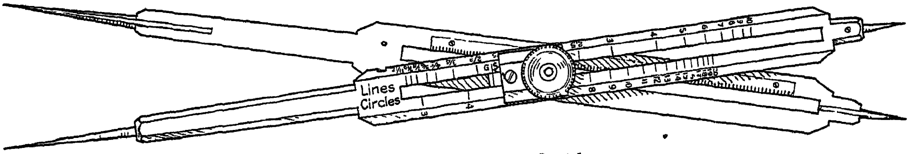


Fig. 1029.—Proportional dividers.

In an emergency the *rubber-band method* of enlarging may be used. Select a band wide enough and mark along it the distances to be enlarged; when the band is stretched, these distances will stretch proportionately.

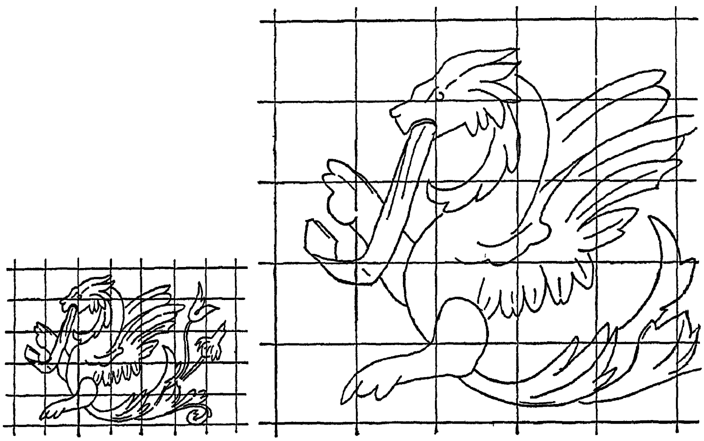


Fig. 1030.—Enlargement by squares.

494. Preserving Drawings.—A drawing, tracing or blueprint which is to be handled much may be varnished with a thin coat of white shellac.

Pencil drawings may be sprayed with fixatif.

Prints made on sensitized cloth will withstand hard usage.

Blueprints for shop use are often mounted for preservation and for convenience in handling, by pasting on tarboard or heavy pressboard and coating with white shellac or Damar varnish. A coat of white glue under the varnish will aid still further in making the drawings washable.

Tracings to which more or less frequent reference will be made should be filed flat in shallow drawers. Sets of drawings preserved only for record are often kept in tin tubes, numbered and filed systematically. A pasteboard tube with screw cover is also made for this purpose. It is lighter than tin and withstands fire and water even better. Fireproof storage vaults should always be provided in connection with drafting rooms.

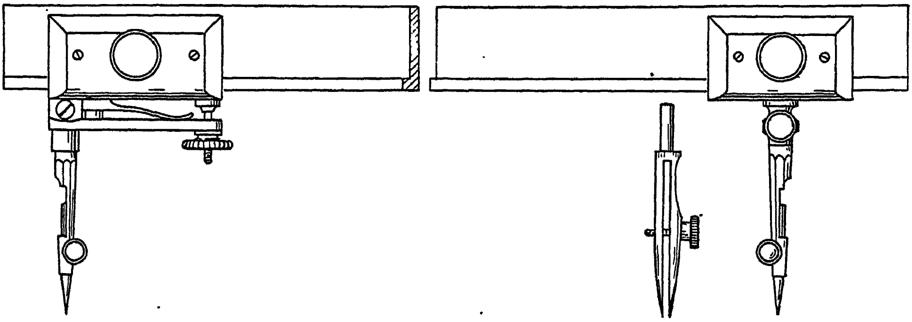


FIG. 1031.—Beam compasses.

495. Special Instruments.—There are some instruments not in the usual assortment that are occasionally needed. Beam compasses are used for circles larger than the capacity of ordinary compasses with lengthening

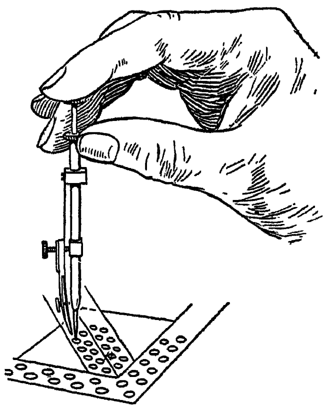


FIG. 1032.—A drop pen.

bar. A good form is illustrated in Fig. 1031. A tubular beam compass is shown in Fig. 7.

With the drop pen or rivet pen, Fig. 1032, smaller circles can be made and made much faster than with the bow pen. It is held as shown, the needle point is stationary, and the pen is revolved around it. It is of particular convenience in bridge and structural work and in topographic drawing.

Several instruments for drawing ellipses have been made. The ellipsograph, Fig. 1033, is a very satisfactory one.

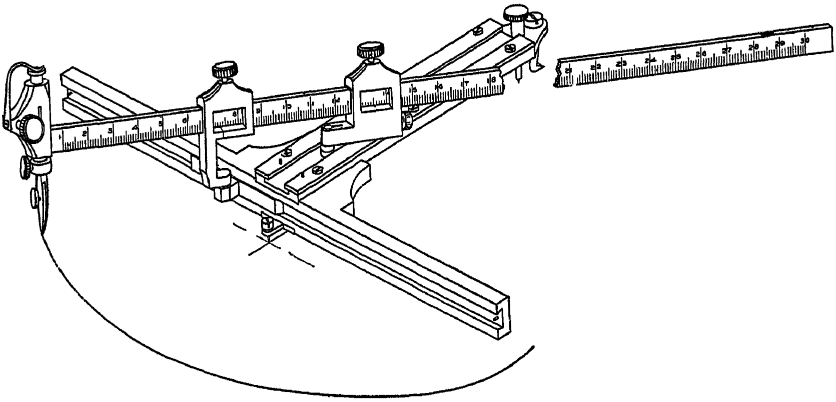


FIG. 1033.—An ellipsograph.

Three special pens are shown in Fig. 1034. The *railroad pen A* is used for double lines. A better pen for double lines up to ¼ inch apart is the *border pen B*, as it can be held down to the paper more satisfactorily. It

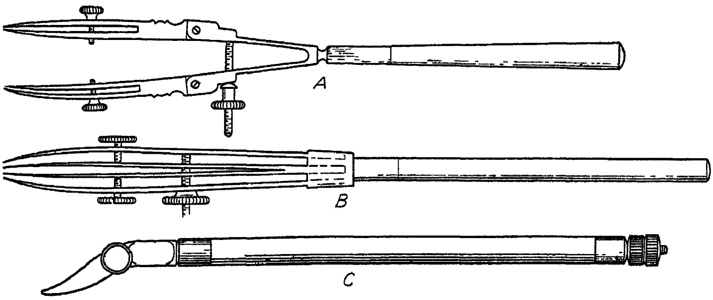


FIG. 1034.—Special pens.

may be used for very wide solid lines by inking the middle space as well as the two pens. The *contour pen* or curve pen *C*, made with a swivel, is used in map work for freehand curves.

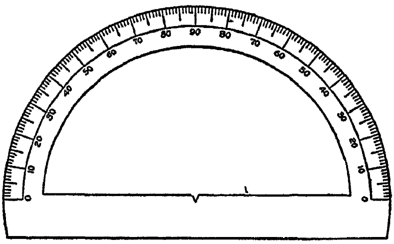


FIG. 1035.—A protractor.

A **protractor** is a necessity in map and topographical work. A semicircular brass or nickel-silver one, 6 inches in diameter, such as the one shown in Fig. 1035, will read to half degrees. They may be had with an

arm and vernier reading to minutes. Large circular paper protractors 8 and 14 inches in diameter reading to half and quarter degrees are used and preferred by some map draftsmen. Others prefer the Brown and Sharpe protractor, Fig. 1036, reading to 5 minutes.

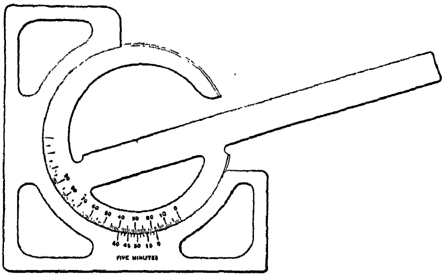


FIG. 1036.—Brown and Sharpe protractor.

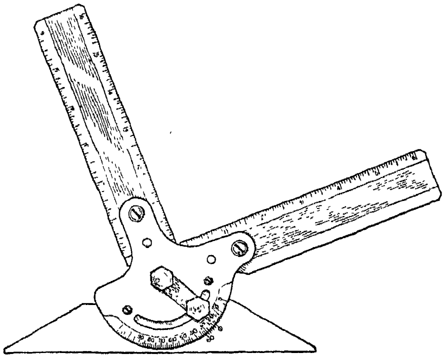


FIG. 1037.—Tri-pro-scale.

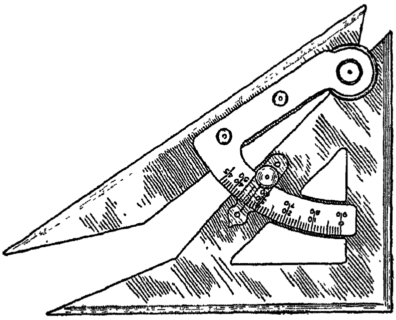


FIG. 1038.—New Facila set-square.

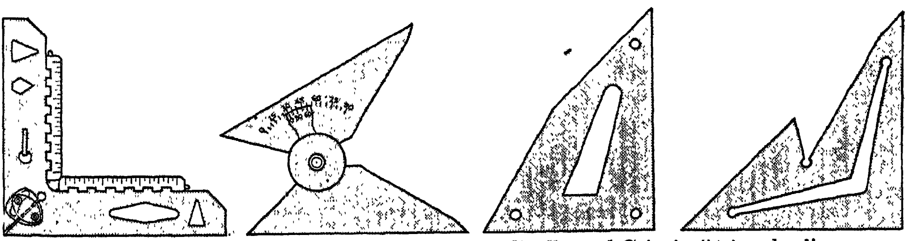


FIG. 1039.—Ware angle square; Lesh, Rondinella and Crispin "triangles."

Two combinations of triangle and protractor popular with architects and draftsmen are shown in Figs. 1037 and 1038. Numerous different forms of combination "triangles" have been devised, of which several are shown in Fig. 1039.

Drafting Machines.—Since the expiration of the patent on the Universal drafting machine several makers have come into competition with varied designs of this important instrument, which combines the functions of

T-square, very accurate plotting may be done. These are often used in bridge offices.

A temporary adjustment of a T-square may be made by putting a thumbtack in the head, Fig. 1045.

If much ruling in red ink is done, a pen for the purpose with nickel-silver blades is advisable.

Painted aluminum sheets are being used instead of paper for large layout and assembly drawings where a fine degree of accuracy is required.

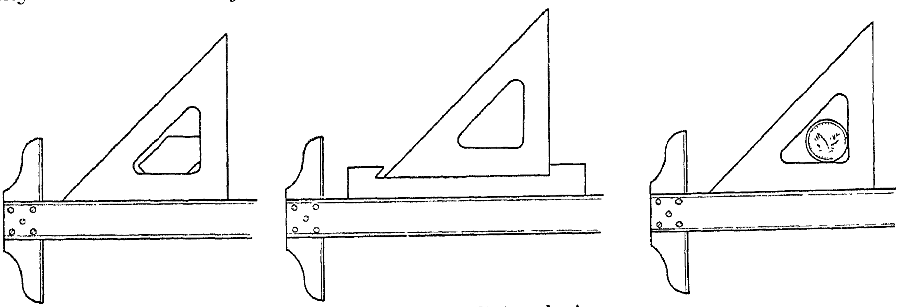


Fig. 1046.—Section-lining devices.

For this the Studebaker Corporation specifies 14-gage "half-hardened" aluminum, primed with one coat of shellac and given eight coats of Acme no-luster white and then rubbed with fine "wetordry" sandpaper and water.

Section lining or "crosshatching" is a difficult operation for the beginner but is done almost automatically by the experienced draftsman. A number of instruments for mechanical spacing have been devised. For ordinary work they are not worth the trouble of setting up, and a draftsman should never become dependent upon them, although they are of occasional value in careful drawing for reproduction. Three ways of making a section liner

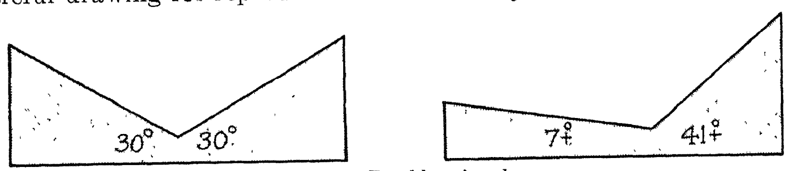


Fig. 1047.—Double triangles.

out of an ordinary triangle are shown in Fig. 1046. The first two may be made of thin wood or celluloid cut in the shapes indicated and used by slipping the block and holding the triangle and then holding the block and slipping the triangle. A coin may be used instead of the block.

Erasing shields of metal or celluloid permit an erasure to be made in a small space. Slots for the same purpose may be cut from sheet celluloid or tough paper.

Double triangles are very convenient in making pictorial drawings. Two forms are shown in Fig. 1047, one for isometric and one for dimetric projection.

Mechanical lettering devices are being much used in drafting rooms. Several forms are on the market, including the Wrico, Edco, Normograph and Leroy, all based on the principle of a stylographic pen guided by a sliding master plate. With their use very satisfactory display lettering can

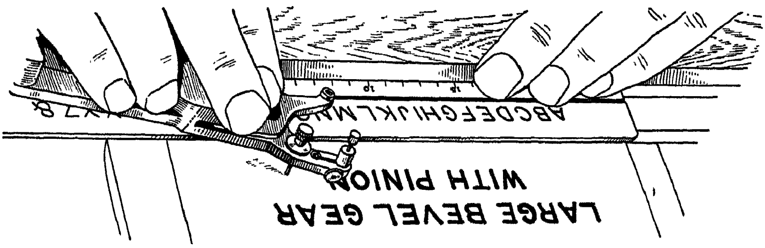


FIG. 1048.—Lettering machine; Leroy.

be done by unskilled labor. Figures 1048 and 1049 illustrate two of these instruments.

There are many other devices designed for labor saving and convenience in drafting rooms. The Bostich tacker is used instead of thumbtacks.

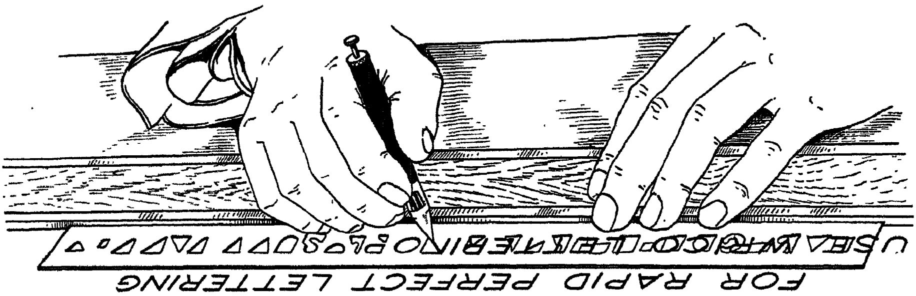


FIG. 1049.—Lettering machine; Wrico.

Many draftsmen like to fasten paper to the board with Scotch tape. For this *drafting tape* should be used in preference to masking tape or other varieties of Scotch tape. The Dexter "Draftsmen's Special" pencil sharpener removes the wood only, leaving a long exposure of lead. Electric erasing machines are popular.

CHAPTER XXXI

BIBLIOGRAPHY OF ALLIED SUBJECTS

The following short classified list of books is given to supplement this book, whose scope as a general treatise on the language of engineering drawing permitted only the mention or brief explanation of some subjects.

Abbreviations used for publishers' names:
Harper—Harper & Brothers, New York.
Int T.—International Textbook Company, Scranton, Pa.
McGH.—McGraw-Hill Book Company, Inc., New York.
Macm.—The Macmillian Company, New York.
PP.—Pencil Points Library (Reinhold Publishing Corporation, New York).
Pitm.—Pitman Publishing Corporation, New York.
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A great many "pocket-size" handbooks, with tables, formulas and information, are published for the different branches of the engineering profession, and draftsmen keep the ones pertaining to their particular line at hand for ready reference. Attention is called, however, to the danger of using handbook formulas and figures without understanding the principles upon which they are based. "Handbook designer" is a term of reproach applied not without reason to one who depends wholly upon these aids without knowing their theory or limitations.

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AMERICAN STANDARDS

The American Standards Association is working on a large number of standardization projects. Of its many publications the following approved standards having to do with the subjects in this book are available at the

time of this printing and may be purchased at cost at its offices, 29 West Thirty-ninth Street, New York. A complete list of American Standards will be sent by the association on application.

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APPENDIX

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APPENDIX

Tapers.—Taper means the difference in diameter or width in 1 foot of length, Fig. 1050 *Taper pins*, much used for fastening cylindrical parts and for doweling, have a standard taper of $\frac{1}{4}''$ per foot.

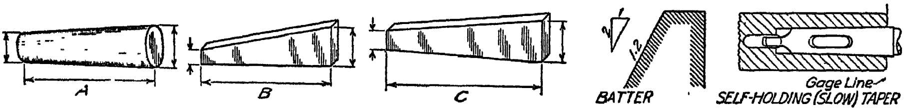


FIG. 1050.

Machine Tapers.—The American Standard for self-holding (slow) machine tapers is designed to replace the various former standards. The table below shows its derivation. Detailed dimensions and tolerances for taper tool shanks and taper sockets will be found in ASA B5.10 1937.

DIMENSIONS OF TAPER PINS
Taper $\frac{1}{4}''$ per foot

Size No.	Diameter, large end	Drill size for reamer	Max. length
000000	0.072	53	$\frac{5}{8}$
00000	0 092	47	$\frac{5}{8}$
0000	0.108	42	$\frac{3}{4}$
000	0 125	37	$\frac{3}{4}$
00	0.147	31	1
0	0.156	28	1
1	0 172	25	$1\frac{1}{4}$
2	0 193	19	$1\frac{1}{2}$
3	0.219	12	$1\frac{3}{4}$
4	0.250	3	2
5	0.289	$\frac{1}{4}$	$2\frac{1}{4}$
6	0.341	$\frac{9}{32}$	$3\frac{1}{4}$
7	0.409	$\frac{11}{32}$	$3\frac{3}{4}$
8	0 492	$\frac{13}{32}$	$4\frac{1}{2}$
9	0.591	$\frac{31}{64}$	$5\frac{1}{4}$
10	0.706	$\frac{19}{32}$	6
11	0.857	$\frac{23}{32}$	$7\frac{1}{4}$
12	1.013	$\frac{55}{64}$	$8\frac{3}{4}$
13	1.233	$1\frac{1}{64}$	$10\frac{3}{4}$

All dimensions in inches.

AMERICAN STANDARD MACHINE TAPERS[1] SELF-HOLDING (SLOW) TAPER SERIES
Basic Dimensions

Origin of series	No. of taper	Taper per foot	Diameter at gage line	Means of driving and holding
Brown and Sharpe taper series	0 239	0 500	0.239	Tongue drive with shank held in by friction
	0 299	0.500	0.299	
	0 375	0.500	0.375	
Morse taper series	1	0.600	0 475	Tongue drive with shank held in by friction; Tongue drive with shank held in by key
	2	0 600	0.700	
	3	0.602	0.938	
	4	0.623	1.231	
	$4\frac{1}{2}$	0.623	1.500	
	5	0.630	1.748	
$\frac{3}{4}''$ per foot taper series	200	0.750	2.000	Tongue drive with shank held in by friction; Tongue drive with shank held in by key; Key drive with shank held in by key; Key drive with shank held in by drawbolt
	250	0.750	2.500	
	300	0.750	3.000	
	350	0.750	3.500	
	400	0.750	4.000	Key drive with shank held in by key; Key drive with shank held in by drawbolt
	500	0.750	5.000	
	600	0.750	6.000	
	800	0.750	8.000	
	1,000	0.750	10.000	
	1,200	0.750	12.000	

All dimensions in inches
[1] ASA B5.10 1937.

Decimal Equivalents of Fractions of an Inch

1/64	= 0.015625	17/64	= 0.265625	33/64	= 0.515625	49/64	= 0 765625
1/32	= 0.03125	9/32	= 0.28125	17/32	= 0.53125	25/32	= 0.78125
3/64	= 0.046875	19/64	= 0.296875	35/64	= 0.546875	51/64	= 0.796875
1/16	= 0.0625	5/16	= 0.3125	9/16	= 0.5625	13/16	= 0.8125
5/64	= 0.078125	21/64	= 0.328125	37/64	= 0.578125	53/64	= 0.828125
3/32	= 0.09375	11/32	= 0.34375	19/32	= 0.59375	27/32	= 0.84375
7/64	= 0.109375	23/64	= 0.359375	39/64	= 0 609375	55/64	= 0.859375
1/8	= 0.125	3/8	= 0.375	5/8	= 0.625	7/8	= 0.875
9/64	= 0.140625	25/64	= 0.390625	41/64	= 0.640625	57/64	= 0.890625
5/32	= 0.15625	13/32	= 0.40625	21/32	= 0 65625	29/32	= 0.90625
11/64	= 0.171875	27/64	= 0.421875	43/64	= 0.671875	59/64	= 0.921875
3/16	= 0.1875	7/16	= 0.4375	11/16	= 0.6875	15/16	= 0.9375
13/64	= 0.203125	29/64	= 0.453125	45/64	= 0.703125	61/64	= 0.953125
7/32	= 0.21875	15/32	= 0.46875	23/32	= 0.71875	31/32	= 0.96875
15/64	= 0.234375	31/64	= 0.484375	47/64	= 0.734375	63/64	= 0.984375
1/4	= 0.25	1/2	= 0.5	3/4	= 0 75	1	= 1.0

Metric Equivalents

In converting inches to millimeters carry the millimeter equivalent to one *less* decimal place than the number to which the inch value is given.

In converting from millimeters to inches carry the inch equivalent to two *more* places than the number to which the millimeter value is given.

Millimeters to inches				Inches to millimeters			
Mm.	In.	Mm.	In.	In.	Mm.	In.	Mm.
1	= 0.0394	17	= 0 6693	1/32	= 0.79	17/32	= 13.49
2	= 0.0787	18	= 0.7087	1/16	= 1.58	9/16	= 14.28
3	= 0.1181	19	= 0.7480	3/32	= 2.38	19/32	= 15.08
4	= 0.1575	20	= 0.7874	1/8	= 3.17	5/8	= 15 87
5	= 0.1968	21	= 0.8268	5/32	= 3.96	21/32	= 16.66
6	= 0.2362	22	= 0.8661	3/16	= 4.76	11/16	= 17.46
7	= 0.2756	23	= 0.9055	7/32	= 5.55	23/32	= 18.25
8	= 0.3150	24	= 0.9449	1/4	= 6.34	3/4	= 19.04
9	= 0.3543	25	= 0.9843	9/32	= 7.14	25/32	= 19.84
10	= 0.3937	26	= 1.0236	5/16	= 7.93	13/16	= 20.63
11	= 0.4331	27	= 1.0630	11/32	= 8.73	27/32	= 21.43
12	= 0.4724	28	= 1.1024	3/8	= 9.52	7/8	= 22.22
13	= 0.5118	29	= 1.1417	13/32	= 10.31	29/32	= 23.01
14	= 0.5512	30	= 1.1811	7/16	= 11.11	15/16	= 23.81
15	= 0.5906	31	= 1.2205	15/32	= 11.90	31/32	= 24.60
16	= 0.6299	32	= 1.2598	1/2	= 12.69	1	= 25.39

AMERICAN STANDARD SCREW THREADS

American Standard Coarse and Fine[1] and SAE Extra-fine Thread Series[2]

Size	Threads per inch: Coarse NC	Fine NF	Extra fine EF (SAE)
0	. .	80	
1	64	72	
2	56	64	
3	48	56	
4	40	48	
5	40	44	
6	32	40	
8	32	36	
10	24	32	
12	24	28	
$\frac{1}{4}$	20	28	36
$\frac{5}{16}$	18	24	32
$\frac{3}{8}$	16	24	32
$\frac{7}{16}$	14	20	28
$\frac{1}{2}$	13	20	28
$\frac{9}{16}$	12	18	24
$\frac{5}{8}$	11	18	24
$\frac{3}{4}$	10	16	20
$\frac{7}{8}$	9	14	20
1	8	14	20
$1\frac{1}{8}$	7	12	18
$1\frac{1}{4}$	7	12	18
$1\frac{3}{8}$	6		
$1\frac{1}{2}$	6	12	18
$1\frac{3}{4}$	5	..	16
2	$4\frac{1}{2}$	..	16
$2\frac{1}{4}$	$4\frac{1}{2}$	..	16
$2\frac{1}{2}$	4	..	16
$2\frac{3}{4}$	4	..	16
3	4	..	16
Over 3	....	..	16

[1] ASA B1.1 1935.
[2] The extra-fine screw thread series of the Society of Automotive Engineers is intended for aeronautical and other applications where screw threads finer than NF are necessary.

American Standard 8-pitch, 12-pitch and 16-pitch Thread Series[1]

Size	Threads per inch: 8-pitch N8	12-pitch N12	16-pitch N16
$\frac{1}{2}$ to $\frac{11}{16}$[2]	..	12	
$\frac{3}{4}$ to $\frac{15}{16}$[2]	..	12	16
1	8	12	16
$1\frac{1}{16}$	..	12	16
$1\frac{1}{8}$	8	12	16
$1\frac{3}{16}$	..	12	16
$1\frac{1}{4}$	8	12	16
$1\frac{5}{16}$	..	12	16
$1\frac{3}{8}$	8	12	16
$1\frac{7}{16}$	..	12	16
$1\frac{1}{2}$	8	12	16
$1\frac{9}{16}$	..	..	16
$1\frac{5}{8}$	8	12	16
$1\frac{11}{16}$	..	..	16
$1\frac{3}{4}$	8	12	16
$1\frac{13}{16}$	..	..	16
$1\frac{7}{8}$	8	12	16
$1\frac{15}{16}$	..	..	16
2	8	12	16
$2\frac{1}{16}$	..	..	16
$2\frac{1}{8}$	8	12	16
$2\frac{3}{16}$	..	..	16
$2\frac{1}{4}$	8	12	16
$2\frac{5}{16}$	..	..	16
$2\frac{3}{8}$	..	12	16
$2\frac{7}{16}$	..	..	16
$2\frac{1}{2}$	8	12	16
$2\frac{5}{8}$	..	12	16
$2\frac{3}{4}$	8	12	16
$2\frac{7}{8}$	..	12	16
3	8	12	16
$3\frac{1}{8}$	..	12	16
$3\frac{1}{4}$	8	12	16
$3\frac{3}{8}$	..	12	16
$3\frac{1}{2}$	8	12	16
$3\frac{5}{8}$	..	12	16
$3\frac{3}{4}$	8	12	16
$3\frac{7}{8}$	..	12	16
4	8	12	16
$4\frac{1}{4}$ to 6[3]	8	12	

[1] ASA B1.1 1935.
[2] Size increments, $\frac{1}{16}''$.
[3] Size increments, $\frac{1}{4}''$.

American Standard Wrench-head Bolts and Nuts[1]—Regular Series

Diameter	Heads: unfinished, square and hexagon; semifinished, hexagon only — Width — Across flats (W), sq. and hex.	Heads — Width — Across corners — Sq.	Heads — Width — Across corners — Hex.	Heads — Height (H) — Unfin.	Heads — Height (H) — Semifin.	Nuts: unfinished, square and hexagon; semifinished, hexagon only — Width — Across flats (W), sq. and hex.	Nuts — Width — Across corners — Sq.	Nuts — Width — Across corners — Hex.	Nuts — Thickness (T) — Regular — Unfin.	Nuts — Thickness (T) — Regular — Semifin.	Nuts — Thickness (T) — Jam — Unfin.	Nuts — Thickness (T) — Jam — Semifin.	Nuts — Thickness (T) — Slotted — Semifin.	Nuts — Slotted — Slot — Width	Nuts — Slotted — Slot — Depth
1/4	3/8	1/2	13/32	11/64	5/32	7/16	37/64	31/64	7/32	13/64	5/32	9/64	13/64	5/64	3/32
5/16	1/2	43/64	35/64	13/64	3/16	9/16	3/4	5/8	17/64	1/4	3/16	11/64	1/4	3/32	3/32
3/8	9/16	3/4	5/8	1/4	15/64	5/8	53/64	11/16	21/64	5/16	7/32	13/64	5/16	1/8	1/8
7/16	5/8	53/64	11/16	19/64	9/32	3/4	1	53/64	3/8	23/64	1/4	15/64	23/64	1/8	5/32
1/2	3/4	1	53/64	21/64	19/64	13/16	1 5/64	57/64	7/16	27/64	5/16	19/64	27/64	5/32	5/32
9/16	7/8	1 5/32	31/32	3/8	11/32	7/8	1 5/32	1 31/32	1/2	31/64	11/32	21/64	31/64	5/32	3/16
5/8	15/16	1 1/4	1 1/32	27/64	25/64	1	1 21/64	1 7/64	35/64	17/32	3/8	23/64	17/32	3/16	7/32
3/4	1 1/8	1 1/2	1 15/64	1/2	15/32	1 1/8	1 1/2	1 1/4	21/32	41/64	7/16	27/64	41/64	3/16	1/4
7/8	1 5/16	1 47/64	1 29/64	19/32	9/16	1 5/16	1 47/64	1 29/64	49/64	3/4	1/2	31/64	3/4	3/16	1/4
1	1 1/2	1 63/64	1 21/32	21/32	19/32	1 1/2	1 63/64	1 21/32	7/8	55/64	9/16	35/64	55/64	1/4	9/32
1 1/8	1 11/16	2 15/64	1 55/64	3/4	11/16	1 11/16	2 15/64	1 55/64	1	31/32	5/8	39/64	31/32	1/4	11/32
1 1/4	1 7/8	2 31/64	2 1/16	27/32	25/32	1 7/8	2 31/64	2 1/16	1 3/32	1 1/16	3/4	23/32	1 1/16	5/16	3/8
1 3/8	2 1/16	2 47/64	2 17/64	29/32	27/32	2 1/16	2 47/64	2 17/64	1 13/64	1 11/64	13/16	25/32	1 11/64	5/16	3/8
1 1/2	2 1/4	2 63/64	2 31/64	1	15/16	2 1/4	2 63/64	2 31/64	1 5/16	1 9/32	7/8	27/32	1 9/32	3/8	7/16
1 5/8	2 7/16	3 15/64	2 11/16	1 3/32	1 1/32	2 7/16	3 15/64	2 11/16	1 27/64	1 25/64	15/16	29/32	1 25/64	3/8	7/16
1 3/4	2 5/8	3 31/64	2 57/64	1 5/32	1 3/32	2 5/8	3 31/64	2 57/64	1 17/32	1 1/2	1	31/32	1 1/2	7/16	1/2
1 7/8	2 13/16	3 47/64	3 3/32	1 1/4	1 3/16	2 13/16	3 47/64	3 3/32	1 41/64	1 39/64	1 1/16	1 1/32	1 39/64	7/16	9/16
2	3	3 63/64	3 5/16	1 11/32	1 7/32	3	3 63/64	3 5/16	1 3/4	1 23/32	1 1/8	1 3/32	1 23/32	7/16	9/16
2 1/4	3 3/8	4 31/64	3 23/32	1 1/2	1 3/8	3 3/8	4 41/64	3 23/32	1 31/32	1 59/64	1 1/4	1 13/64	1 59/64	7/16	9/16
2 1/2	3 3/4	4 63/64	4 9/64	1 21/32	1 17/32	3 3/4	4 63/64	4 9/64	2 3/16	2 9/64	1 1/2	1 29/64	2 9/64	9/16	11/16
2 3/4	4 1/8	5 15/32	4 35/64	1 13/16	1 11/16	4 1/8	.....	.....	2 13/32	2 23/64	1 5/8	1 37/64	2 23/64	9/16	11/16
3	4 1/2	5 31/32	4 61/64	2	1 7/8	4 1/2	...	...	2 5/8	2 37/64	1 3/4	1 45/64	2 37/64	5/8	3/4

All dimensions in inches. [1] ASA B18.2 1941.

AMERICAN STANDARD WRENCH-HEAD BOLTS AND NUTS[1]—Heavy Series

Diameter[2]	Heads: unfinished, square and hexagon; semifinished, hexagon only					Nuts: unfinished, square and hexagon; semifinished, hexagon only									
	Width			Height (*H*)		Width			Thickness (*T*)						
									Heavy		Jam		Slotted		
	Across flats (*W*), sq. and hex.	Across corners				Across flats (*W*), sq. and hex.	Across corners							Slot	
		Sq.	Hex.	Unfin.	Semifin.		Sq.	Hex.	Unfin.	Semifin.	Unfin.	Semifin.	Semifin.	Width	Depth
1/4	.....	.....	.....	.....	.....	1/2	43/64	9/16	1/4	15/64	3/16	11/64	15/64	5/64	3/32
5/16	.....	.....	.....	.....	.....	19/32	51/64	21/32	5/16	19/64	7/32	13/64	19/64	3/32	3/32
3/8	.....	.....	.....	.....	.....	11/16	59/64	49/64	3/8	23/64	1/4	15/64	23/64	1/8	1/8
7/16	.....	.....	.....	.....	.....	25/32	1 3/64	55/64	7/16	27/64	9/32	17/64	27/64	1/8	5/32
1/2	7/8	1 11/64	31/32	7/16	13/32	7/8	1 11/64	31/32	1/2	31/64	5/16	19/64	31/64	5/32	5/32
9/16	15/16	1 1/4	1 1/32	15/32	7/16	15/16	1 1/4	1 1/32	9/16	35/64	11/32	21/64	35/64	5/32	3/16
5/8	1 1/16	1 27/64	1 11/64	17/32	1/2	1 1/16	1 27/64	1 11/64	5/8	39/64	3/8	23/64	39/64	3/16	7/32
3/4	1 1/4	1 43/64	1 3/8	5/8	19/32	1 1/4	1 43/62	1 3/8	3/4	47/64	7/16	27/64	47/64	3/16	1/4
7/8	1 7/16	1 59/64	1 19/32	23/32	11/16	1 7/16	1 59/64	1 19/32	7/8	55/64	1/2	31/64	55/64	3/16	1/4
1	1 5/8	2 5/32	1 51/64	13/16	3/4	1 5/8	2 5/32	1 51/64	1	63/64	9/16	35/64	63/64	1/4	9/32
1 1/8	1 13/16	2 13/32	2	29/32	27/32	1 13/16	2 13/32	2	1 1/8	1 7/64	5/8	39/64	1 7/64	1/4	11/32
1 1/4	2	2 21/32	2 13/64	1	15/16	2	2 21/32	2 13/64	1 1/4	1 7/32	3/4	23/32	1 7/32	5/16	3/8
1 3/8	2 3/16	2 29/32	2 27/64	1 3/32	1 1/32	2 3/16	2 29/32	2 27/64	1 3/8	1 11/32	13/16	25/32	1 11/32	5/16	3/8
1 1/2	2 3/8	3 5/32	2 5/8	1 3/16	1 1/8	2 3/8	3 5/32	2 5/8	1 1/2	1 15/32	7/8	27/32	1 15/32	3/8	7/16
1 5/8	2 9/16	3 13/32	2 53/64	1 9/32	1 7/32	2 9/16	3 13/32	2 53/64	1 5/8	1 19/32	15/16	29/32	1 19/32	3/8	7/16
1 3/4	2 3/4	3 21/32	3 1/32	1 3/8	1 5/16	2 3/4	3 21/32	3 1/32	1 3/4	1 23/32	1	31/32	1 23/32	7/16	1/2
1 7/8	2 15/16	3 29/32	3 15/64	1 15/32	1 13/32	2 15/16	3 29/32	3 15/64	1 7/8	1 27/32	1 1/16	1 1/32	1 27/32	7/16	9/16
2	3 1/8	4 5/32	3 29/64	1 9/16	1 7/16	3 1/8	4 5/32	3 29/64	2	1 31/32	1 1/8	1 3/32	1 31/32	7/16	9/16
2 1/4	3 1/2	4 21/32	3 55/64	1 3/4	1 5/8	3 1/2	4 21/32	3 55/64	2 1/4	2 13/64	1 1/4	1 13/64	2 13/64	7/16	9/16
2 1/2	3 7/8	5 5/32	4 9/32	1 15/16	1 13/16	3 7/8	5 5/32	4 9/32	2 1/2	2 29/64	1 1/2	1 29/64	2 29/64	9/16	11/16
2 3/4	4 1/4	5 41/64	4 11/16	2 1/8	2	4 1/4	5 41/64	4 11/16	2 3/4	2 45/64	1 5/8	1 37/64	2 45/64	9/16	11/16
3	4 5/8	6 9/64	5 7/64	2 5/16	2 3/16	4 5/8	6 9/64	5 7/64	3	2 61/64	1 3/4	1 45/64	2 61/64	5/8	3/4

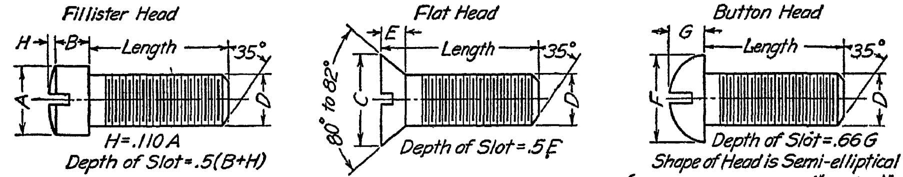
All dimensions in inches. [1] ASA B18.2 1941. [2] For diameters over 3″ see ASA B18.2 1941.

American Standard Nuts[1]—Light Series, Semifinished, Hexagon Only

Thread diameter	Width: All light series nuts, Across flats (W)	Width: All light series nuts, Across corners	Thickness: Castle nuts, T	Thickness: Castle nuts, Height[2] of flats	Thickness: Jam nuts, T	Thickness: Light and light slotted nuts, T	Thickness: Light thick and light thick slotted nuts, T	Slots: All slotted nuts, Width	Slots: All slotted nuts, Depth
1/4	7/16	31/64	9/32	3/16	5/32	7/32	9/32	5/64	3/32
5/16	1/2	9/16	21/64	15/64	3/16	17/64	21/64	3/32	3/32
3/8	9/16	5/8	13/32	9/32	7/32	21/64	13/32	1/8	1/8
7/16	5/8	45/64	29/64	19/64	1/4	3/8	29/64	1/8	5/32
1/2	3/4	27/32	9/16	13/32	5/16	7/16	9/16	5/32	5/32
9/16	7/8	63/64	39/64	27/64	5/16	31/64	39/64	5/32	3/16
5/8	15/16	1 3/64	23/32	1/2	3/8	35/64	23/32	3/16	7/32
3/4	1 1/16	1 3/16	13/16	9/16	3/8	21/32	13/16	3/16	1/4
7/8	1 1/4	1 13/32	29/32	21/32	7/16	49/64	29/32	3/16	1/4
1	1 7/16	1 39/64	1	23/32	1/2	7/8	1	1/4	9/32
1 1/8	1 5/8	1 53/64	1 5/32	13/16	9/16	63/64	1 5/32	1/4	11/32
1 1/4	1 13/16	2 1/32	1 1/4	7/8	5/8	1 3/32	1 1/4	5/16	3/8
1 3/8	2	2 1/4	1 3/8	1	3/4	1 13/64	1 3/8	5/16	3/8
1 1/2	2 3/16	2 15/32	1 1/2	1 1/16	13/16	1 5/16	1 1/2	3/8	7/16

All dimensions in inches. [1] ASA B18.2 1941.
[2] Height of the hexagon is measured from the bearing surface to the top of arc.

Dimensions[1] of Slotted-head Cap Screws[2]—Compiled from American Standard



Length of Thread = 2D + 1/4"
Width of Slots = .160D + .024"

Standard Length Increments — for screw lengths 1/4" to 1" = 1/8"; for screw lengths 1" to 4" = 1/4"; for screw lengths 4" to 6" = 1/2"

Diameter D of screw	A	B	C	E	F	G
1/4	3/8	11/64	1/2	0.146	7/16	3/16
5/16	7/16	13/64	5/8	0.183	9/16	15/64
3/8	9/16	1/4	3/4	0.220	5/8	1/4
7/16	5/8	19/64	13/16	0.220	3/4	5/16
1/2	3/4	21/64	7/8	0.220	13/16	21/64
9/16	13/16	3/8	1	0.256	15/16	25/64
5/8	7/8	27/64	1 1/8	0.293	1	7/16
3/4	1	1/2	1 3/8	0.366	1 1/4	17/32
7/8	1 1/8	19/32				
1	1 15/16	21/32				

All dimensions in inches. [1] Nominal. [2] ASA B18c 1930.

American Standard Bolts—Recommended Minimum Thread Lengths[1]

Bolt length[2]	No. 10, 1/4	5/16, 3/8	7/16, 1/2	9/16, 5/8	3/4	7/8	1	1 1/8, 1 1/4	1 3/8, 1 1/2	1 5/8, 1 3/4	1 7/8, 2	2 1/4	2 1/2	2 3/4	3
	Nominal diameter of bolt — Minimum thread length														
3/4	1/2	1/2													
1	3/4	3/4	3/4	3/4											
1 1/4	3/4	3/4	1	1	1										
1 1/2	3/4	7/8	1	1 1/8	1 1/8	1 1/8									
1 3/4	3/4	7/8	1	1 3/16	1 3/8	1 3/8	1 3/8								
2	3/4	1	1 1/4	1 1/4	1 3/8	1 9/16	1 5/8	1 5/8							
2 1/2	3/4	1	1 1/4	1 1/2	1 1/2	1 9/16	1 3/4	2	2						
3	7/8	1	1 1/4	1 1/2	1 3/4	1 3/4	1 3/4	2 1/8	2 1/2	2 1/2					
4	7/8	1	1 1/4	1 1/2	1 3/4	2	2 1/4	2 1/4	2 1/2	2 7/8	3 1/4	3 1/4	3 1/4		
5	7/8	1 3/16	1 1/4	1 1/2	1 3/4	2	2 1/4	2 3/4	2 3/4	2 7/8	3 1/4	3 5/8	4	4 1/8	4 1/4
6	7/8	1 3/16	1 1/2	1 1/2	1 3/4	2	2 1/4	2 3/4	3 1/4	3 1/4	3 1/4	3 5/8	4	4 1/8	4 3/4
8	7/8	1 3/16	1 1/2	1 13/16	2	2	2 1/4	2 3/4	3 1/4	3 3/4	4	4	4	4 1/8	4 3/4
10	7/8	1 3/16	1 1/2	1 13/16	2 1/8	2 7/16	2 1/2	2 3/4	3 1/4	3 3/4	4 1/4	4 3/4	4 3/4	4 3/4	4 3/4
12	7/8	1 3/16	1 1/2	1 13/16	2 1/8	2 7/16	2 3/4	2 3/4	3 1/4	3 3/4	4 1/4	4 3/4	5 1/4	5 3/4	6 1/4
16	1	1 3/16	1 1/2	1 13/16	2 1/8	2 7/16	2 3/4	3 1/4	3 1/4	3 3/4	4 1/4	4 3/4	5 1/4	5 3/4	6 1/4
20	1	1 3/8	1 1/2	1 13/16	2 1/8	2 7/16	2 3/4	3 3/8	4	4 5/8	4 3/4	4 3/4	5 1/4	5 3/4	6 1/4
30	...	....	1 3/4	1 13/16	2 1/8	2 7/16	2 3/4	3 3/8	4	4 5/8	5 1/4	5 7/8	6 1/2	6 1/2	6 1/2

All dimensions in inches.

Minimum thread length is measured from the end of the bolt to the last complete thread.

For bolts too short for the specified thread lengths, threads shall be cut or rolled to within 1/4 in. of head or neck on sizes up to and including 1/2 in.; 3/8 in. on sizes 9/16 to 1 in., inclusive; 1/2 in. on sizes 1 1/8 to 2 in., inclusive; and 3/4 in. on sizes 2 1/8 to 3 in., inclusive.

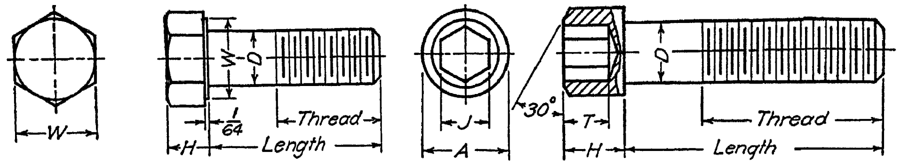
Length of incomplete thread shall not exceed 2 1/2 threads.

The thread lengths shown in this table have been inserted as showing the usual practice followed by manufacturers when American Standard bolts are ordered and are applicable to both Regular and Heavy Series.

[1] Recommended by the American Standards Association but not a part of the American Standards.

[2] For intermediate bolt lengths, the minimum thread length shall be the same as that specified in the table for the next shorter length of bolt of the same diameter.

AMERICAN STANDARD CAP SCREWS



Diameter D	Threads per inch: Coarse	Threads per inch: Fine[3]	Hexagon[1]: Width across flats W	Hexagon[1]: Height of head H	Socket hexagon[2]: A	Socket hexagon[2]: H	Socket hexagon[2]: J	Socket hexagon[2]: T
1/4	20	28	7/16	3/16	3/8	1/4	3/16	Socket depth is not specified by the standards. Exact depth may be obtained from manufacturers' catalogues. For drawing purposes $T = \frac{3}{4}H$
5/16	18	24	1/2	15/64	7/16	5/16	7/32	
3/8	16	24	9/16	9/32	9/16	3/8	5/16	
7/16	14	20	5/8	21/64	5/8	7/16	5/16	
1/2	13	20	3/4	3/8	3/4	1/2	3/8	
9/16	12	18	13/16	27/64	13/16	9/16	3/8	
5/8	11	18	7/8	15/32	7/8	5/8	1/2	
3/4	10	16	1	9/16	1	3/4	9/16	
7/8	9	14	1 1/8	21/32	1 1/8	7/8	9/16	
1	8	14	1 5/16	3/4	1 5/16	1	5/8	
1 1/8	7	12	1 1/2	27/32	1 1/2	1 1/8	3/4	
1 1/4	7	12	1 11/16	15/16	1 3/4	1 1/4	3/4	

Body-length increments: For screw lengths 1/4 to 1 = 1/8″; For screw lengths 1″ to 4″ = 1/4″; For screw lengths 4″ to 6″ = 1/2″

Thread length: Coarse thread: $2D + \frac{1}{2}''$; Fine thread: $1\frac{1}{2}D + \frac{1}{2}''$

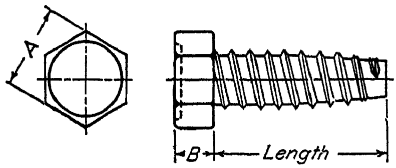
All dimensions in inches.

[1] ASA B18.2 1940.

[2] ASA B18.3 1936.

[3] Not included in American Standards but in common use.

PARKER-KALON SELF-TAPPING CAP SCREWS—Compiled from Parker-Kalon Catalogue

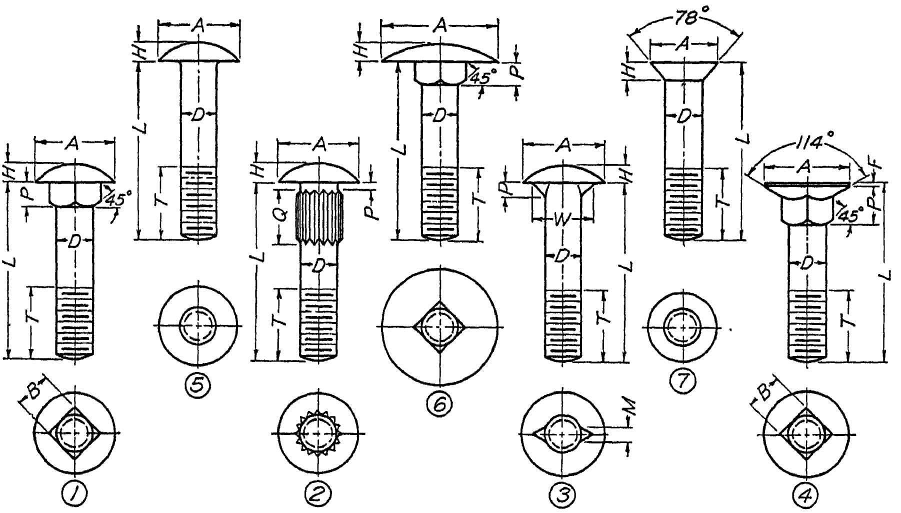


Diameter	A	B	Length (L)[1]	Drill size: Aluminum die castings, etc.	Drill size: Slate, ebony, asbestos, etc.
6	1/4	5/64	3/16, 3/8, 1/4, 3/16	No. 30	No. 31
8	1/4	7/64	1/4″ to 1″ by (1/8″)	No. 24	No. 26
10	9/32	1/4	3/8″ to 1″ by (1/8″)	No.16	No. 19
14	3/8	11/64	3/8″ to 1 1/2″ by (1/8″)	15/64	No. 1
5/16	1/2	13/64	1/2″ to 1″ by (1/8″) 1 1/4, 1 1/2	L	9/32
3/8	9/16	9/32	5/8″ to 1″ by (1/8″) 1″ to 2″ by (1/4″)	S	21/64
7/16	5/8	5/16	3/4″ to 1″ by (1/8″) 1″ to 2″ by (1/4″)	Z	X
1/2	3/4	3/8	3/4″ to 1″ by (1/8″) 1″ to 2 1/2″ by (1/4″)	15/32	29/64

[1] Fractions in parentheses show length increments, for example, 1/4 to 1″ by (1/8″) included the lengths 1/4″, 3/8″, 1/2″, 5/8″, 3/4″, 7/8″ and 1″.

American Standard Round Unslotted-head Bolts

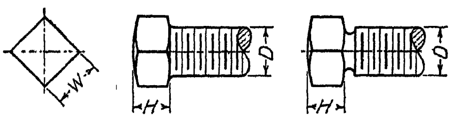
Compiled from ASA B18.5 1939



Fastening		Nominal diameter[1]	A	H	P and M	B	F	W	Q Rib neck only
Carriage bolts	① Square neck	No. 10, 1/4″ to 5/8″ by (1/16″); 5/8″ to 1″ by (1/8″)	$2D + 1/16$	$\frac{D}{2}$	$\frac{D}{2} + 1/16$	D			3/16″ for bolt lengths 7/8″ or less; 5/16″ for bolt lengths 1″ and 1 1/8″; 1/2″ for bolt lengths 1 1/4″ and more
Carriage bolts	② Rib neck	No. 10, 1/4″ to 5/8″ by (1/16″); 5/8″ and 3/4″	$2D + 1/16$	$\frac{D}{2}$	1/16				
Carriage bolts	③ Fin neck	No. 10, 1/4″ to 1/2″ by (1/16″)	$2D + 3/32$	$\frac{D}{2} - 1/64$	$3/8D$			1 1/2 + 1/16	
Carriage bolts	④ Counter sunk	No. 10, 3/4″; 1/4″ to 5/8″ by (1/16″)	$2D + 1/8$	....	$D + 1/32$	D	1/32	NOTE.—The proportions in this table are for drawing purposes. Thread lengths for drawing are $2D + 1/4$. For exact dimensions see ASA B18 5 1939. [1] Fractions in parentheses show diameter increments, for example, 1/4″ to 5/8″ by (1/16″) includes the diameters 1/4″, 5/16″, 3/8″, 7/16″, 1/2″, 9/16″ and 5/8″.	
⑤ Button-head bolt		No. 10, 1/4″ to 5/8″ by (1/16″) 5/8″ to 1″ by (1/8″)	$2D + 1/16$	$\frac{D}{2}$					
⑥ Step bolt		No. 10, 1/4″ to 1/2″ by (1/16″)	$3D + 1/16$	$\frac{D}{2}$	$\frac{D}{2} + 1/16$	D			
⑦ Counter-sunk bolt		1/2″ to 5/8″ by (1/16″); 5/8″ to 2″ by (1/8″)	Obtain by projection	$\frac{D}{2}$					

American Standard Square-headed Setscrews

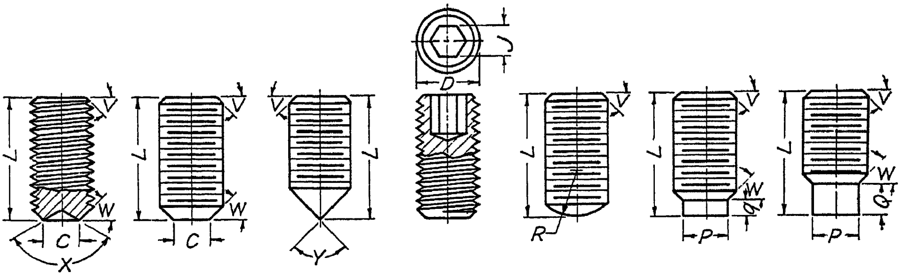
Threads Are American Standard[1]



Diameter	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2
Width across flats W	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2
Height of head H	3/16	15/64	9/32	21/64	3/8	27/64	15/32	9/16	21/32	3/4	27/32	15/16	1 1/32	1 1/8

[1] ASA B18.2 1940.

American Standard Hexagonal Socket Setscrews
Compiled from ASA B18.3 1936

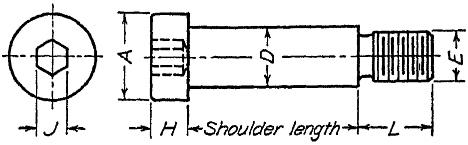


Cup Point *Flat Point* *Cone Point* *Oval Point* *Half Dog Point* *Full Dog Point*

Diameter D	Cup and flat-point diameter C	Oval-point radius R	Cone-point angle Y for these lengths and under: 118° ± 2°	Cone-point angle Y: 90° ± 2°	Full and half dog points: Diameter P	Length: Full Q	Length: Half q	Socket width J
5	1/16	3/32	1/8	3/16	0.083	0.06	0.03	1/16
6	0.069	7/64	1/8	3/16	0.092	0.07	0.03	1/16
8	5/64	1/8	3/16	1/4	0.109	0.08	0.04	5/64
10	3/32	9/64	3/16	1/4	0.127	0.09	0.04	3/32
12	7/64	5/32	3/16	1/4	0.144	0.11	0.06	3/32
1/4	1/8	3/16	1/4	5/16	5/32	1/8	1/16	1/8
5/16	11/64	15/64	5/16	3/8	13/64	5/32	5/64	5/32
3/8	13/64	9/32	3/8	7/16	1/4	3/16	3/32	3/16
7/16	15/64	21/64	7/16	1/2	19/64	7/32	7/64	7/32
1/2	9/32	3/8	1/2	9/16	11/32	1/4	1/8	1/4
9/16	5/16	27/64	9/16	5/8	25/64	9/32	9/64	1/4
5/8	23/64	15/32	5/8	3/4	15/32	5/16	5/32	5/16
3/4	7/16	9/16	3/4	7/8	9/16	3/8	3/16	3/8
7/8	33/64	21/32	7/8	1	21/32	7/16	7/32	1/2
1	19/32	3/4	1	1 1/8	3/4	1/2	1/4	9/16
1 1/8	43/64	27/32	1 1/8	1 1/4	27/32	9/16	9/32	9/16
1 1/4	3/4	15/16	1 1/4	1 1/2	15/16	5/8	5/16	5/8
1 3/8	53/64	1 1/32	1 3/8	1 5/8	1 1/32	11/16	11/32	5/8
1 1/2	29/32	1 1/8	1 1/2	1 3/4	1 1/8	3/4	3/8	3/4
1 3/4	1 1/16	1 5/16	1 3/4	2	1 5/16	7/8	7/16	1
2	1 7/32	1 1/2	2	2 1/4	1 1/2	1	1/2	1

All dimensions in inches.
Chamfer and point angle.
W = 45°, +5°, −0°, draw 45°.
X = 118° ±5°; draw 120°.
V and Z = 35° + 5°, −0°; draw 45°.
Standard length increments: 1/4″ to 5/8″ by (1/16″); 5/8″ to 1″ by (1/8″); 1″ to 4″ by (1/4″); 4″ to 6″ by (1/2″). Fractions in parentheses show length increments; for example, 5/8″ to 1″ by (1/8″) includes the lengths 5/8″, 3/4″, 7/8″, and 1″.

Stripper Bolts or Shoulder Screws



Shoulder diameter D		Head			Thread[1]		Shoulder lengths[2]
Nominal	Limits	Diameter A	Height H	Hexagon J	Diameter E	Length L	
3/8	0.373 / 0.370	9/16	1/4	3/16	5/16	1/2	1"–4" by (1/4")
1/2	0.498 / 0.494	3/4	5/16	1/4	3/8	5/8	1"–5" by (1/4")
5/8	0.623 / 0.619	7/8	3/8	5/16	1/2	3/4	1"–5" by (1/4") 5"–6" by (1/2")
3/4	0.748 / 0.744	1	1/2	3/8	5/8	7/8	1"–5" by (1/4") 5"–7" by (1/2")

Dimensions in inches.
[1] Threads are Am. Std. Coarse.
[2] Fractions in parentheses show shoulder-length increments, for example, 1" to 4" by (1/4") includes the lengths 1", 1 1/4", 1 1/2", 1 3/4", 2", 2 1/4", 2 1/2", 2 3/4", 3", 3 1/4", 3 1/2", 3 3/4" and 4".

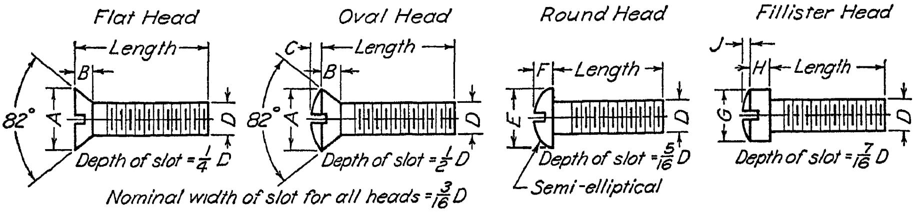
Tap-drill Sizes
For 75 Per Cent Depth of Thread

Fractional						Machine screw			Pipe tap[2]		
Tap size	Threads[1] per inch	Drill	Tap size	Threads per inch	Drill	Tap size	Threads per inch	Drill	Tap size	Threads per inch	Drill
1/8	40 NS	38		9 NC	49/64	0	80 NF	3/64	1/8	27	11/32
3/16	24 NS	26	7/8	14 NF	13/16	1	64 NC	53	1/4	18	7/16
1/4	20 NC	7		18 NS	53/64		72 NF	53	3/8	18	37/64
	28 NF	3	15/16	9 NS	53/64	2	56 NC	50	1/2	14	23/32
5/16	18 NC	*F*	1	8 NC	7/8		64 NF	49	3/4	14	59/64
	24 NF	*I*		14 NF	15/16	3	48 NC	46	1	11 1/2	1 5/32
3/8	16 NC	5/16	1 1/8	7 NC	63/64		56 NF	45	1 1/4	11 1/2	1 1/2
	24 NF	*Q*		12 NF	1 3/64	4	36 NS	44	1 1/2	11 1/2	1 47/64
7/16	14 NC	*U*	1 1/4	7 NC	1 7/64		40 NC	43	2	11 1/2	2 7/32
	20 NF	25/64		12 NF	1 11/64		48 NF	42	2 1/2	8	2 5/8
1/2	13 NC	27/64	1 3/8	6 NC	1 13/64	5	40 NC	38	3	8	3 1/4
	20 NF	29/64		12 NF	1 19/64		44 NF	37	3 1/2	8	3 3/4
9/16	12 NC	31/64	1 1/2	6 NC	1 11/32	6	32 NC	35	4	8	4 1/4
	18 NF	33/64		12 NF	1 27/64		40 NF	33			
5/8	11 NC	17/32	1 5/8	5 1/2 NS	1 29/64	8	32 NC	29			
	18 NF	37/64	1 3/4	5 NC	1 9/16		36 NF	29			
11/16	11 NS	19/32	1 7/8	5 NS	1 11/16	10	24 NC	25			
	16 NS	5/8	2	4 1/2 NC	1 25/32		32 NF	21			
3/4	10 NC	21/32				12	24 NC	16			
	16 NF	11/16					28 NF	14			
13/16	10 NS	23/32				14	20 NS	10			
							24 NS	7			

[1] NS = National Special; NC = National Coarse; NF = National Fine.
[2] All sizes N.P.T. (American Standard Pipe thread).

Dimensions of Machine Screws and Machine-screw and Stove-bolt Nuts

Compiled from Formulas of American Standards



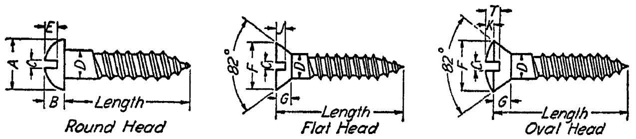
Nominal size	Diameter D	Threads per in. (coarse)	Threads per in. (fine)	A	B	C	E	F	G	H	J
2	0.086	56	64	0 164	0 046	0.041	0.154	0 065	0 132	0 050	0.023
3	0.099	48	56	0 190	0 054	0.048	0 178	0 073	0 153	0 058	0 027
4	0 112	40	48	0 216	0.061	0.054	0.202	0 081	0 175	0 066	0 030
5	0.125	40	..	0.242	0 069	0.061	0.227	0 089	0.198	0.075	0 033
6	0.138	32	40	0 268	0.076	0.067	0.250	0 097	0.217	0 083	0.037
8	0.164	32	36	0.320	0 092	0.080	0 298	0.113	0.260	0 099	0.043
10	0 190	24	32	0 372	0.107	0 094	0.346	0.130	0 303	0 115	0.049
12	0.216	24	28	0.424	0.122	0.107	0 395	0 146	0.344	0 132	0.056
1/4	0.250	20	28	0.492	0.142	0 124	0 458	0.168	0 402	0 153	0 064
5/16	0.3125	18	24	0 618	0.179	0.156	0.574	0 207	0 505	0.193	0 080
3/8	0.375	16	24	0 742	0.215	0.186	0.689	0.247	0.606	0.232	0.096

Nominal Size		2	3	4	5	6	8	10	12	1/4	5/16	3/8
Machine-screw[1] and Stove-bolt[2] Nuts	W	3/16	3/16	1/4	5/16	5/16	11/32	3/8	7/16	7/16	9/16	5/8
	T	1/16	1/16	3/32	7/64	7/64	1/8	1/8	5/32	3/16	7/32	1/4

Dimensions in inches. [1] Machine-screw nuts are hexagonal. [2] Stove-bolt nuts are square.

Dimensions of Wood Screws

Compiled from ASA B18c 1930



Screw No.	Diameter D	A	B	C	E	F	G	J	K	T
0	0.060	0.106	0.047	0 025	0.034	0.112	0.030	0.012	0.018	0 027
1	0.073	0.130	0.056	0.027	0.038	0.138	0.038	0.015	0 022	0.034
2	0.086	0.154	0.064	0 030	0 042	0.164	0.045	0.019	0.025	0.041
3	0.099	0.178	0.072	0.032	0 046	0 190	0 053	0.022	0 029	0.047
4	0.112	0 202	0 080	0.034	0 050	0.216	0.061	0.025	0.033	0 054
5	0.125	0.228	0.089	0.037	0.054	0 242	0.068	0.028	0.037	0.061
6	0.138	0 250	0 097	0.039	0.058	0.268	0.076	0.031	0.040	0.067
7	0.151	0.274	0.105	0.041	0.062	0 294	0.083	0.034	0.044	0.073
8	0.164	0.298	0.113	0 043	0.066	0.320	0.092	0.037	0.048	0.080
9	0.177	0.322	0.121	0.045	0.070	0.346	0.100	0.040	0.051	0.086
10	0.190	0.346	0.130	0.048	0.075	0.371	0.107	0.043	0.055	0.093
11	0.203	0.370	0.138	0.050	0 078	0.398	0.114	0.046	0.059	0.100
12	0.216	0.395	0.146	0.052	0.083	0.424	0.123	0.049	0.063	0.116
14	0.242	0.443	0.162	0.057	0.091	0.476	0.137	0.056	0.069	0.120
16	0.268	0.491	0.178	0.061	0.099	0.528	0.152	0.062	0.077	0.133
18	0.294	0.539	0.195	0.066	0.107	0.580	0.167	0.068	0.085	0.146

Dimensions in inches.

Recommended[1] SAE Standard Lock Washers

Screw or bolt size, nominal	SAE standard sizes			Lock washers for use with					
	SAE Light	SAE Standard[2]	SAE Heavy	All regular boltheads and nuts, Series A	Cap screws, Series B	Round head mach. screws, Series C	Fillister head mach. screws, Series D	Mach.-screw and stovebolt nuts, Series E	Socket-head cap screws
2*	0.022 × 0.022	1/32 × 0.022	1/32 × 1/32	...	..	.	1/32 × 0.022		
2†	1/32 × 0.022	1/32 × 1/32	3/64 × 1/32	...	....	1/32 × 1/32			
4*	1/32 × 0.022	1/32 × 1/32	3/64 × 1/32	.			1/32 × 1/32	......	0.022 × 0.022
4†	3/64 × 1/32	1/16 × 1/32	5/64 × 1/32	..	.	3/64 × 1/32			
6*	1/32 × 1/32	3/64 × 1/32	3/64 × 3/64	..		.	3/64 × 1/32	....	1/32 × 1/32
6†	1/16 × 1/32	5/64 × 1/32	5/64 × 3/64	.	.	1/16 × 3/64	....	3/32 × 3/64	
8*	3/64 × 1/32	3/64 × 3/64	1/16 × 3/64	..		..	1/16 × 3/64	......	3/64 × 3/64
8†	5/64 × 1/32	5/64 × 3/64	3/32 × 3/64	.....	..	5/64 × 3/64	....	7/64 × 1/16	
10*	3/64 × 3/64	1/16 × 3/64	1/16 × 1/16	...	...	...	1/16 × 3/64	....	3/64 × 3/64
10†	5/64 × 3/64	3/32 × 3/64	3/32 × 1/16	..	...	3/32 × 1/16	...	7/64 × 1/16	
1/4	3/32 × 3/64	3/32 × 1/16	3/32 × 5/64	9/64 × 5/64	1/8 × 1/16	1/8 × 1/16	5/64 × 1/16	9/64 × 5/64	3/64 × 5/64
5/16	1/8 × 3/64	1/8 × 1/16	1/8 × 3/32	5/32 × 3/32	9/64 × 5/64	9/64 × 5/64	7/64 × 1/16	5/32 × 3/32	3/64 × 5/64
3/8	1/8 × 1/16	1/8 × 3/32	1/8 × 1/8	11/64 × 7/64	5/32 × 3/32	5/32 × 3/32	1/8 × 3/32	11/64 × 7/64	5/64 × 1/8
7/16	5/32 × 1/16	5/32 × 1/8	5/32 × 5/32	13/64 × 1/8	11/64 × 7/64	......	.....	......	5/64 × 1/8
1/2	11/64 × 1/16	11/64 × 1/8	11/64 × 11/64	7/32 × 5/32	3/16 × 1/8	....	.....	....	7/64 × 11/64
9/16	3/16 × 3/32	3/16 × 1/8	3/16 × 3/16	1/4 × 3/16	13/64 × 1/8				
5/8	13/64 × 3/32	13/64 × 5/32	13/64 × 13/64	17/64 × 3/16	7/32 × 5/32	.....	....	.....	7/64 × 11/64
3/4	1/4 × 1/8	1/4 × 3/16	1/4 × 1/4	5/16 × 7/32	1/4 × 3/16	....	....	.....	7/64 × 3/16
7/8	17/64 × 5/32	17/64 × 3/16	17/64 × 17/64	11/32 × 1/4	5/16 × 7/32	......	....	.....	7/64 × 3/16
1	5/16 × 3/16	5/16 × 1/4	5/16 × 5/16	13/32 × 9/32	5/16 × 1/4	...	......	.....	1/8 × 13/64
1 1/8	3/8 × 3/16	3/8 × 1/4	3/8 × 3/8	7/16 × 5/16	11/32 × 1/4	....	....	....	5/32 × 5/16
1 1/4	7/16 × 3/16	7/16 × 1/4	7/16 × 5/16	1/2 × 3/8	3/8 × 5/16	....	....	....	7/32 × 5/16
1 3/8	7/16 × 1/4	7/16 × 5/16	7/16 × 3/8	1/2 × 3/8	3/8 × 5/16	....	....	....	
1 1/2	1/2 × 1/4	1/2 × 5/16	1/2 × 3/8	1/2 × 3/8	3/8 × 5/16	....	....	....	7/32 × 5/16

The first fraction in dimension is width, the second thickness. Dimensions in inches.
* For fillister-headed machine screws.
† For round-head machine screws.
[1] By Spring Washer Industry.
[2] Also called "Regular."

SAE Standard Plain Washers

Nominal size..........	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2
Inside diameter.......	9/32	11/32	13/32	15/32	17/32	19/32	21/32	23/32	13/16	15/16	1 1/16	1 3/16	1 5/16	1 7/16	1 9/16
Outside diameter......	5/8	11/16	13/16	15/16	1 1/16	1 3/16	1 5/16	1 3/8	1 1/2	1 3/4	2	2 1/4	2 1/2	3/4	3
Thickness............	1/16	1/16	1/16	1/16	3/32	3/32	3/32	3/32	1/8	1/8	1/8	1/8	5/32	5/32	5/32

Dimensions in inches.

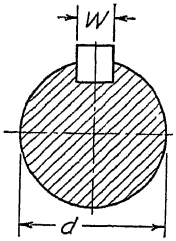
Bolt-length Increments[1]

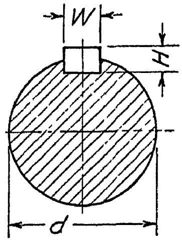
Bolt diameter		1/4	5/16	3/8	7/16	1/2	5/8	3/4	7/8	1
Length Increments	1/4	3/4–3	3/4–4	3/4–6	1–3	1–6	1–6	1–6	1–4 1/2	
	1/2	3–4	4–5	6–9	3–6	6–13	6–10	6–15	4 1/2–6	3–6
	1	4–5	...	9–12	6–8	13–24	10–22	15–24	6–20	6–12
	2	...	...	....	...	.....	22–30	24–30	20–30	12–30

Example: 1/4″ bolt lengths increase by 1/4″ increments from 3/4″ to 3″ length. 1/2″ bolt lengths increase by 1/2″ increments from 6″ to 13″ length. 1″ bolt lengths increase by 2″ increments from 12″ to 30″ length.
[1] Compiled from manufacturers' catalogues.

Widths and Heights of Standard Square and Flat Stock Keys with Corresponding Shaft Diameters

Approved by American Standards Association
ASA B17.1 1934



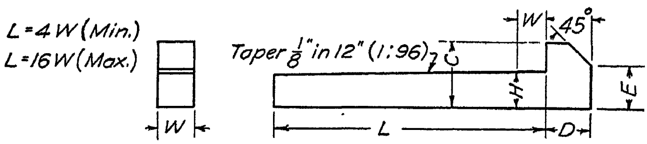


Shaft diameter *d* (inclusive)	Square-stock keys, *W*	Flat-stock keys, *W* × *H*	Shaft diameter *d* (inclusive)	Square-stock keys *W*	Flat-stock keys, *W* × *H*
1/2 - 9/16	1/8	1/8 × 3/32	2 7/8–3 1/4	3/4	3/4 × 1/2
5/8 - 7/8	3/16	3/16 × 1/8	3 3/8–3 3/4	7/8	7/8 × 5/8
15/16–1 1/4	1/4	1/4 × 3/16	3 7/8–4 1/2	1	1 × 3/4
1 5/16–1 3/8	5/16	5/16 × 1/4			
1 7/16–1 3/4	3/8	3/8 × 1/4	4 3/4–5 1/2	1 1/4	1 1/4 × 7/8
1 13/16–2 1/4	1/2	1/2 × 3/8	5 3/4–6	1 1/2	1 1/2 × 1
2 5/16–2 3/4	5/8	5/8 × 7/16			

Dimensions in inches.

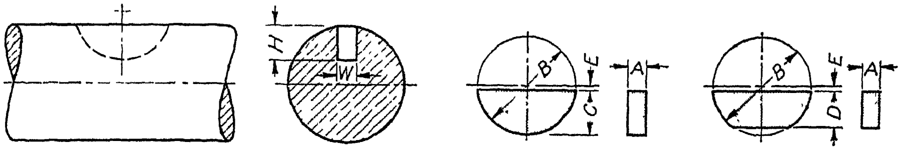
Dimensions of Standard Gib-head Keys, Square and Flat

Approved by American Standards Association
ASA B17.1 1934



Diameters of shafts	Square type					Flat type				
	Key		Gib head			Key		Gib head		
	W	*H*	*C*	*D*	*E*	*W*	*H*	*C*	*D*	*E*
1/2 - 9/16	1/8	1/8	1/4	7/32	5/32	1/8	3/32	3/16	1/8	1/8
5/8 - 7/8	3/16	3/16	5/16	9/32	7/32	3/16	1/8	1/4	3/16	5/32
15/16–1 1/4	1/4	1/4	7/16	11/32	11/32	1/4	3/16	5/16	1/4	3/16
1 5/16–1 3/8	5/16	5/16	9/16	13/32	13/32	5/16	1/4	3/8	5/16	1/4
1 7/16–1 3/4	3/8	3/8	11/16	15/32	15/32	3/8	1/4	7/16	3/8	5/16
1 13/16–2 1/4	1/2	1/2	7/8	19/32	5/8	1/2	3/8	5/8	1/2	7/16
2 5/16–2 3/4	5/8	5/8	1 1/16	23/32	3/4	5/8	7/16	3/4	5/8	1/2
2 7/8 -3 1/4	3/4	3/4	1 1/4	7/8	7/8	3/4	1/2	7/8	3/4	5/8
3 3/8 -3 3/4	7/8	7/8	1 1/2	1	1	7/8	5/8	1 1/16	7/8	3/4
3 7/8 -4 1/2	1	1	1 3/4	1 3/16	1 3/16	1	3/4	1 1/4	1	13/16
4 3/4 -5 1/2	1 1/4	1 1/4	2	1 7/16	1 7/16	1 1/4	7/8	1 1/2	1 1/4	1
5 3/4 -6	1 1/2	1 1/2	2 1/2	1 3/4	1 3/4	1 1/2	1	1 3/4	1 1/2	1 1/4

Dimensions in inches.



WOODRUFF KEY AND KEY-SLOT DIMENSIONS[1]

Key[2] No.	Nominal size	Maximum width of key A	Maximum diameter of key B	Maximum height of key C	Maximum height of key D	Distance below center E	Key slot W	Key slot H
204	1/16 × 1/2	0.0635	0.500	0.203	0.194	3/64	0.0630	0.1718
304	3/32 × 1/2	0.0948	0.500	0.203	0.194	3/64	0.0943	0.1561
305	3/32 × 5/8	0.0948	0.625	0.250	0.240	1/16	0.0943	0.2031
404	1/8 × 1/2	0.1260	0.500	0.203	0.194	3/64	0.1255	0.1405
405	1/8 × 5/8	0.1260	0.625	0.250	0.240	1/16	0.1255	0.1875
406	1/8 × 3/4	0.1260	0.750	0.313	0.303	1/16	0.1255	0.2505
505	5/32 × 5/8	0.1573	0.625	0.250	0.240	1/16	0.1568	0.1719
506	5/32 × 3/4	0.1573	0.750	0.313	0.303	1/16	0.1568	0.2349
507	5/32 × 7/8	0.1573	0.875	0.375	0.365	1/16	0.1568	0.2969
606	3/16 × 3/4	0.1885	0.750	0.313	0.303	1/16	0.1880	0.2193
607	3/16 × 7/8	0.1885	0.875	~~0.375~~	0.365	1/16	0.1880	0.2813
608	3/16 × 1	0.1885	1.000	0.438	0.428	1/16	0.1880	0.3443
609	3/16 × 1 1/8	0.1885	1.125	0.484	0.475	5/64	0.1880	0.3902
807	1/4 × 7/8	0.2510	0.875	0.375	0.365	1/16	0.2505	0.2500
808	1/4 × 1	0.2510	1.000	0.438	0.428	1/16	0.2505	0.3130
809	1/4 × 1 1/8	0.2510	1.125	0.484	0.475	5/64	0.2505	0.3590
810	1/4 × 1 1/4	0.2510	1.250	0.547	0.537	5/64	0.2505	0.4220
811	1/4 × 1 3/8	0.2510	1.375	0.594	0.584	3/32	0.2505	0.4690
812	1/4 × 1 1/2	0.2510	1.500	0.641	0.631	7/64	0.2505	0.5160
1008	5/16 × 1	0.3135	1.000	0.438	0.428	1/16	0.3130	0.2818
1009	5/16 × 1 1/8	0.3135	1.125	0.484	0.475	5/64	0.3130	0.3278
1010	5/16 × 1 1/4	0.3135	1.250	0.547	0.537	5/64	0.3130	0.3908
1011	5/16 × 1 3/8	0.3135	1.375	0.594	0.584	3/32	0.3130	0.4378
1012	5/16 × 1 1/2	0.3135	1.500	0.641	0.631	7/64	0.3130	0.4848
1210	3/8 × 1 1/4	0.3760	1.250	0.547	0.537	5/64	0.3755	0.3595
1211	3/8 × 1 3/8	0.3760	1.375	0.594	0.584	3/32	0.3755	0.4065
1212	3/8 × 1 1/2	0.3760	1.500	0.641	0.631	7/64	0.3755	0.4535

Dimensions in inches.

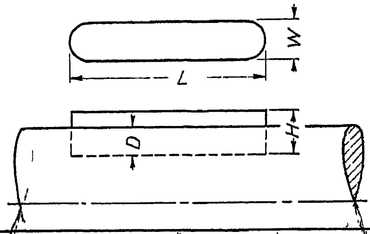
[1] From ASA B17f, 1930.

[2] Key numbers indicate the nominal key dimensions. The last two digits give the nominal diameter (B) in eighths of an inch and the digits preceding the last two give the nominal width (A) in thirty-seconds of an inch. Thus, 204 indicates a key 2/32 by 4/8, or 1/16 by 1/2 inch.

Key-slot Cutters.—Two series of key-slot cutters, fine and coarse teeth, are standard. Both have a shank diameter of 1/2″ for all sizes. They are designated by the key numbers used to designate the size of the key. It will be noted that the depth H is measured from the sharp edge of the slot, not from the shaft circumference on the center line of the key, and therefore does not indicate the depth to which the cutter should be fed into the shaft. The shaft is brought against the cutter until a flat the same width as the thickness of the cutter is formed; the cutter is then fed into the shaft the required depth

Dimensions of Pratt and Whitney Keys

Pratt and Whitney round-end feather keys are in extensive use. The length L may vary but should never be less than $2W$.



Key No.	L	W	H	D	Key No.	L	W	H	D
1	1/2	1/16	3/32	1/16	22	1 3/8	1/4	3/8	1/4
2	1/2	3/32	9/64	3/32	23	1 3/8	5/16	15/32	5/16
3	1/2	1/8	3/16	1/8	F	1 3/8	3/8	9/16	3/8
4	5/8	3/32	9/64	3/32	24	1 1/2	1/4	3/8	1/4
5	5/8	1/8	3/16	1/8	25	1 1/2	5/16	15/32	5/16
6	5/8	5/32	15/64	5/32	G	1 1/2	3/8	9/16	3/8
7	3/4	1/8	3/16	1/8	51	1 3/4	1/4	3/8	1/4
8	3/4	5/32	15/64	5/32	52	1 3/4	5/16	15/32	5/16
9	3/4	3/16	9/32	3/16	53	1 3/4	3/8	9/16	3/8
10	7/8	5/32	15/64	5/32	26	2	3/16	9/32	3/16
11	7/8	3/16	9/32	3/16	27	2	1/4	3/8	1/4
12	7/8	7/32	21/64	7/32	28	2	5/16	15/32	5/16
A	7/8	1/4	3/8	1/4	29	2	3/8	9/16	3/8
13	1	3/16	9/32	3/16	54	2 1/4	1/4	3/8	1/4
14	1	7/32	21/64	7/32	55	2 1/4	5/16	15/32	5/16
15	1	1/4	3/8	1/4	56	2 1/4	3/8	9/16	3/8
B	1	5/16	15/32	5/16	57	2 1/4	7/16	21/32	7/16
16	1 1/8	3/16	9/32	3/16	58	2 1/2	5/16	15/32	5/16
17	1 1/8	7/32	21/64	7/32	59	2 1/2	3/8	9/16	3/8
18	1 1/8	1/4	3/8	1/4	60	2 1/2	7/16	21/32	7/16
C	1 1/8	5/16	15/32	5/16	61	2 1/2	1/2	3/4	1/2
19	1 1/4	3/16	9/32	3/16	30	3	3/8	9/16	3/8
20	1 1/4	7/32	21/64	7/32	31	3	7/16	21/32	7/16
21	1 1/4	1/4	3/8	1/4	32	3	1/2	3/4	1/2
D	1 1/4	5/16	15/32	5/16	33	3	9/16	27/32	9/16
E	1 1/4	3/8	9/16	3/8	34	3	5/8	15/16	5/8

Dimensions in inches.
Key is 2/3 in shaft; 1/3 in hub.
Keys are 0.001 inch oversize in width to ensure proper fitting in keyway.
Keyway size: width = W; depth = $H - D$.

TABLE OF LIMITS FOR CYLINDRICAL FITS
Compiled from American Standard ASA B4a 1925

Size of hole or external member inclusive	Limits															
	Class 1 Loose fit				Class 2 Free fit				Class 3 Medium fit				Class 4 Snug fit			
	Hole or external member		Shaft or internal member		Hole or external member		Shaft or internal member		Hole or external member		Shaft or internal member		Hole or external member		Shaft or internal member	
	+		−	−	+		−	−	+		−	−	+			−
0–3/16	0.001	0.000	0.001	0.002	0.0007	0.0000	0.0004	0.0011	0.0004	0.0000	0.0002	0.0006	0.0003	0.0000	0.0000	0.0002
3/16–5/16	0.002	0.000	0.001	0.003	0.0008	0.0000	0.0006	0.0014	0.0005	0.0000	0.0004	0.0009	0.0004	0.0000	0.0000	0.0003
5/16–7/16	0.002	0.000	0.001	0.003	0.0009	0.0000	0.0007	0.0016	0.0006	0.0000	0.0005	0.0011	0.0004	0.0000	0.0000	0.0003
7/16–9/16	0.002	0.000	0.002	0.004	0.0010	0.0000	0.0009	0.0019	0.0006	0.0000	0.0006	0.0012	0.0005	0.0000	0.0000	0.0003
9/16–11/16	0.002	0.000	0.002	0.004	0.0011	0.0000	0.0010	0.0021	0.0007	0.0000	0.0007	0.0014	0.0005	0.0000	0.0000	0.0003
11/16–13/16	0.002	0.000	0.002	0.004	0.0012	0.0000	0.0012	0.0024	0.0007	0.0000	0.0007	0.0014	0.0005	0.0000	0.0000	0.0004
13/16–15/16	0.002	0.000	0.002	0.004	0.0012	0.0000	0.0013	0.0025	0.0008	0.0000	0.0008	0.0016	0.0006	0.0000	0.0000	0.0004
15/16–1 1/16	0.003	0.000	0.003	0.006	0.0013	0.0000	0.0014	0.0027	0.0008	0.0000	0.0009	0.0017	0.0006	0.0000	0.0000	0.0004
1 1/16–1 3/16	0.003	0.000	0.003	0.006	0.0014	0.0000	0.0015	0.0029	0.0008	0.0000	0.0010	0.0018	0.0006	0.0000	0.0000	0.0004
1 3/16–1 3/8	0.003	0.000	0.003	0.006	0.0014	0.0000	0.0016	0.0030	0.0009	0.0000	0.0010	0.0019	0.0006	0.0000	0.0000	0.0004
1 3/8–1 5/8	0.003	0.000	0.003	0.006	0.0015	0.0000	0.0018	0.0033	0.0009	0.0000	0.0012	0.0021	0.0007	0.0000	0.0000	0.0005
1 5/8–1 7/8	0.003	0.000	0.004	0.007	0.0016	0.0000	0.0020	0.0036	0.0010	0.0000	0.0013	0.0023	0.0007	0.0000	0.0000	0.0005
1 7/8–2 1/8	0.003	0.000	0.004	0.007	0.0016	0.0000	0.0022	0.0038	0.0010	0.0000	0.0014	0.0024	0.0008	0.0000	0.0000	0.0005
2 1/8–2 3/8	0.003	0.000	0.004	0.007	0.0017	0.0000	0.0024	0.0041	0.0010	0.0000	0.0015	0.0025	0.0008	0.0000	0.0000	0.0005
2 3/8–2 3/4	0.003	0.000	0.005	0.008	0.0018	0.0000	0.0026	0.0044	0.0011	0.0000	0.0017	0.0028	0.0008	0.0000	0.0000	0.0005
2 3/4–3 1/4	0.004	0.000	0.005	0.009	0.0019	0.0000	0.0029	0.0048	0.0012	0.0000	0.0019	0.0031	0.0009	0.0000	0.0000	0.0006
3 1/4–3 3/4	0.004	0.000	0.006	0.010	0.0020	0.0000	0.0032	0.0052	0.0012	0.0000	0.0021	0.0033	0.0009	0.0000	0.0000	0.0006
3 3/4–4 1/4	0.004	0.000	0.006	0.010	0.0021	0.0000	0.0035	0.0056	0.0013	0.0000	0.0023	0.0036	0.0010	0.0000	0.0000	0.0006
4 1/4–4 3/4	0.004	0.000	0.007	0.011	0.0021	0.0000	0.0038	0.0059	0.0013	0.0000	0.0025	0.0038	0.0010	0.0000	0.0000	0.0007
4 3/4–5 1/2	0.004	0.000	0.007	0.011	0.0022	0.0000	0.0041	0.0063	0.0014	0.0000	0.0026	0.0040	0.0010	0.0000	0.0000	0.0007
5 1/2–6 1/2	0.005	0.000	0.008	0.013	0.0024	0.0000	0.0046	0.0070	0.0015	0.0000	0.0030	0.0045	0.0011	0.0000	0.0000	0.0007
6 1/2–7 1/2	0.005	0.000	0.009	0.014	0.0025	0.0000	0.0051	0.0076	0.0015	0.0000	0.0033	0.0048	0.0011	0.0000	0.0000	0.0008
7 1/2–8 1/2	0.005	0.000	0.010	0.015	0.0026	0.0000	0.0056	0.0082	0.0016	0.0000	0.0036	0.0052	0.0012	0.0000	0.0000	0.0008

All dimensions in inches.

TABLE OF LIMITS FOR CYLINDRICAL FITS—(*Continued*)
Compiled from American Standard ASA B4a 1925

Size of hole or external member, inclusive	Limits															
	Class 5 Wringing fit				Class 6 Tight fit				Class 7 Medium force fit				Class 8 Heavy force and shrink fit			
	Hole or external member		Shaft or internal member		Hole or external member		Shaft or internal member		Hole or external member		Shaft or internal member		Hole or external member		Shaft or internal member	
	+		+		+		+	+	+		+	+	+		+	+
0 –3/16	0.0003	0.0000	0.0002	0.0000	0.0003	0.0000	0.0003	0.0000	0.0003	0.0000	0.0004	0.0001	0.0003	0.0000	0.0004	0.0001
3/16–5/16	0.0004	0.0000	0.0003	0.0000	0.0004	0.0000	0.0005	0.0001	0.0004	0.0000	0.0005	0.0001	0.0004	0.0000	0.0007	0.0003
5/16–7/16	0.0004	0.0000	0.0003	0.0000	0.0004	0.0000	0.0005	0.0001	0.0004	0.0000	0.0006	0.0002	0.0004	0.0000	0.0008	0.0004
7/16–9/16	0.0005	0.0000	0.0003	0.0000	0.0005	0.0000	0.0006	0.0001	0.0005	0.0000	0.0008	0.0003	0.0005	0.0000	0.0010	0.0005
9/16–11/16	0.0005	0.0000	0.0003	0.0000	0.0005	0.0000	0.0007	0.0002	0.0005	0.0000	0.0008	0.0003	0.0005	0.0000	0.0011	0.0006
11/16–13/16	0.0005	0.0000	0.0004	0.0000	0.0005	0.0000	0.0007	0.0002	0.0005	0.0000	0.0009	0.0004	0.0005	0.0000	0.0013	0.0008
13/16–15/16	0.0006	0.0000	0.0004	0.0000	0.0006	0.0000	0.0008	0.0002	0.0006	0.0000	0.0010	0.0004	0.0006	0.0000	0.0015	0.0009
15/16–1 1/16	0.0006	0.0000	0.0004	0.0000	0.0006	0.0000	0.0009	0.0003	0.0006	0.0000	0.001	0.0005	0.0006	0.0000	0.0016	0.0010
1 1/16–1 3/16	0.0006	0.0000	0.0004	0.0000	0.0006	0.0000	0.0009	0.0003	0.0006	0.0000	0.0012	0.0006	0.0006	0.0000	0.0017	0.0011
1 3/16–1 3/8	0.0006	0.0000	0.0004	0.0000	0.0006	0.0000	0.0009	0.0003	0.0006	0.0000	0.0012	0.0006	0.0006	0.0000	0.0019	0.0013
1 3/8 –1 5/8	0.0007	0.0000	0.0005	0.0000	0.0007	0.0000	0.0011	0.0004	0.0007	0.0000	0.0015	0.0008	0.0007	0.0000	0.0022	0.0015
1 5/8 –1 7/8	0.0007	0.0000	0.0005	0.0000	0.0007	0.0000	0.0011	0.0004	0.0007	0.0000	0.0016	0.0009	0.0007	0.0000	0.0025	0.0018
1 7/8 –2 1/8	0.0008	0.0000	0.0005	0.0000	0.0008	0.0000	0.0013	0.0005	0.0008	0.0000	0.0018	0.0010	0.0008	0.0000	0.0028	0.0020
2 1/8 –2 3/8	0.0008	0.0000	0.0005	0.0000	0.0008	0.0000	0.0014	0.0006	0.0008	0.0000	0.0019	0.0011	0.0008	0.0000	0.0031	0.0023
2 3/8 –2 3/4	0.0008	0.0000	0.0005	0.0000	0.0008	0.0000	0.0014	0.0006	0.0008	0.0000	0.0021	0.0013	0.0008	0.0000	0.0033	0.0025
2 3/4 –3 1/4	0.0009	0.0000	0.0006	0.0000	0.0009	0.0000	0.0017	0.0008	0.0009	0.0000	0.0024	0.0015	0.0009	0.0000	0.0039	0.0030
3 1/4 –3 3/4	0.0009	0.0000	0.0006	0.0000	0.0009	0.0000	0.0018	0.0009	0.0009	0.0000	0.0027	0.0018	0.0009	0.0000	0.0044	0.0035
3 3/4 –4 1/4	0.0010	0.0000	0.0006	0.0000	0.0010	0.0000	0.0020	0.0010	0.0010	0.0000	0.0030	0.0020	0.0010	0.0000	0.0050	0.0040
4 1/4 –4 3/4	0.0010	0.0000	0.0007	0.0000	0.0010	0.0000	0.0021	0.0011	0.0010	0.0000	0.0033	0.0023	0.0010	0.0000	0.0055	0.0045
4 3/4 –5 1/2	0.0010	0.0000	0.0007	0.0000	0.0010	0.0000	0.0023	0.0013	0.0010	0.0000	0.0035	0.0025	0.0010	0.0000	0.0060	0.0050
5 1/2 –6 1/2	0.0011	0.0000	0.0007	0.0000	0.0011	0.0000	0.0026	0.0015	0.0011	0.0000	0.0041	0.0030	0.0011	0.0000	0.0071	0.0060
6 1/2 –7 1/2	0.0011	0.0000	0.0008	0.0000	0.0011	0.0000	0.0029	0.0018	0.0011	0.0000	0.0046	0.0035	0.0011	0.0000	0.0081	0.0070
7 1/2 –8 1/2	0.0012	0.0000	0.0008	0.0000	0.0012	0.0000	0.0032	0.0020	0.0012	0.0000	0.0052	0.0040	0.0012	0.0000	0.0092	0.0080

Dimensions in inches.

American Standard Pipe[1,5]

Nominal pipe size	Actual outside diameter	Threads per inch	Distance pipe enters fittings	Welded and seamless steel					Welded wrought iron					Double extra strong[4]		
				Nominal wall thickness		Weight, lb. per ft.			Nominal wall thickness		Weight, lb. per ft.			Nominal wall thickness		Weight, lb. per ft.
						Schedule 40[2]		Schedule 80[3]			Schedule 40[2]		Schedule 80[3]			
				Schedule 40[2]	Schedule 80[3]	Plain ends	Threads and couplings	Plain ends	Schedule 40[2]	Schedule 80[3]	Plain ends	Threads and couplings	Plain ends	Wrought iron	Steel	
1/8	0.405	27	3/16	0.068	0.095	0.25	0.25	0.32	0.070	0.098	0.25	0.25	0.32			
1/4	0.540	18	9/32	0.088	0.119	0.43	0.43	0.54	0.090	0.122	0.43	0.43	0.54			
3/8	0.675	18	19/64	0.091	0.126	0.57	0.57	0.74	0.093	0.129	0.57	0.57	0.74			
1/2	0.840	14	3/8	0.109	0.147	0.86	0.86	1.09	0.111	0.151	0.86	0.86	1.09	0.307	0.294	1.714
3/4	1.050	14	13/32	0.113	0.154	1.14	1.14	1.48	0.115	0.157	1.14	1.14	1.48	0.318	0.308	2.440
1	1.315	11½	1/2	0.133	0.179	1.68	1.69	2.18	0.136	0.183	1.68	1.69	2.18	0.369	0.358	3.659
1¼	1.660	11½	35/64	0.140	0.191	2.28	2.29	3.00	0.143	0.195	2.28	2.29	3.00	0.393	0.382	5.214
1½	1.900	11½	9/16	0.145	0.200	2.72	2.74	3.64	0.148	0.204	2.72	2.74	3.64	0.411	0.400	6.408
2	2.375	11½	37/64	0.154	0.218	3.66	3.68	5.03	0.158	0.223	3.66	3.68	5.03	0.447	0.436	9.029
2½	2.875	8	7/8	0.203	0.276	5.80	5.82	7.67	0.208	0.282	5.80	5.82	7.67	0.565	0.552	13.695
3	3.5	8	15/16	0.216	0.300	7.58	7.62	10.3	0.221	0.306	7.58	7.62	10.3	0.615	0.600	18.583
3½	4.0	8	1	0.226	0.318	9.11	9.21	12.5	0.231	0.325	9.11	9.21	12.5	0.690	0.674	29.541
4	4.5	8	1 1/16	0.237	0.337	10.8	10.9	15.0	0.242	0.344	10.8	10.9	15.0	0.768	0.750	38.552
5	5.563	8	1 5/32	0.258	0.375	14.7	14.9	20.8	0.263	0.383	14.7	14.9	20.8	0.884	0.864	53.160
6	6.625	8	1¼	0.280	0.432	19.0	19.2	28.6	0.286	0.441	19.0	19.2	28.6	0.895	0.875	72.424

Dimensions in inches.

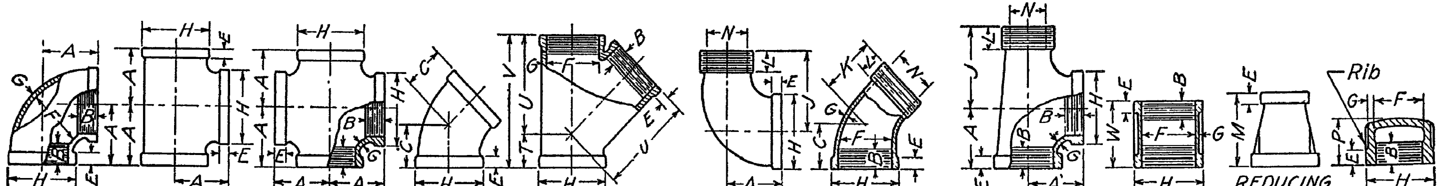
[1] For sizes larger than 6″ see ASA B36.10 1939.

[2] Wall thickness and weights shown under schedule 40 are identical for "Standard weight" pipe in former lists.

[3] Wall thickness and weights shown under schedule 80 are identical for "Extra strong" pipe in former lists.

[4] Not included in present American Standard but is commercially available in both wrought iron and steel.

[5] A pipe size may be designated by giving the nominal pipe size and wall thickness or by giving the nominal pipe size and weight per linear foot.



90° ELBOW TEE CROSS 45° ELL Y BRANCH 90° STREET ELBOW 45° STREET ELBOW STREET TEE COUPLING REDUCING COUPLING CAP

AMERICAN 150-LB. MALLEABLE-IRON SCREWED-FITTING STANDARD[1]

Approved by American Standards Association, July, 1939

Nominal pipe size	*A*	*B*	*C*	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*M*	*N*	*P*	*T*	*U*	*V*	*W*	Thickness of ribs on caps, couplings
1/8	0.69	0.25	....	0.200	0.405	0.090	0.693	1.00[2]	...	0.264	...	0.20	....	...	....	....	0.96	0.090
1/4	0.81	0.32	0.73	0.215	0.540	0.095	0.844	1.19	0.94	0.402	1.00	0.26	....	...	....	....	1.06	0.095
3/8	0.95	0.36	0.80	0.230	0.675	0.100	1.015	1.44	1.03	0.408	1.13	0.37	....	0.50	1.43	1.93	1.16	0.100
1/2	1.12	0.43	0.88	0.249	0.840	0.105	1.197	1.63	1.15	0.534	1.25	0.51	0.87	0.61	1.71	2.32	1.34	0.105
3/4	1.31	0.50	0.98	0.273	1.050	0.120	1.458	1.89	1.29	0.546	1.44	0.69	0.97	0.72	2.05	2.77	1.52	0.120
1	1.50	0.58	1.12	0.302	1.315	0.134	1.771	2.14	1.47	0.683	1.69	0.91	1.16	0.85	2.43	3.28	1.67	0.134
1 1/4	1.75	0.67	1.29	0.341	1.660	0.145	2.153	2.45	1.71	0.707	2.06	1.19	1.28	1.02	2.92	3.94	1.93	0.145
1 1/2	1.94	0.70	1.43	0.368	1.900	0.155	2.427	2.69	1.88	0.724	2.31	1.39	1.33	1.10	3.28	4.38	2.15	0.155
2	2.25	0.75	1.68	0.422	2.375	0.173	2.963	3.26	2.22	0.757	2.81	1.79	1.45	1.24	3.93	5.17	2.53	0.173
2 1/2	2.70	0.92	1.95	0.478	2.875	0.210	3.589	3.86	2.57	1.138	3.25	2.20	1.70	1.52	4.73	6.25	2.88	0.210
3	3.08	0.98	2.17	0.548	3.500	0.231	4.285	4.51	3.00	1.200	3.69	2.78	1.80	1.71	5.55	7.26	3.18	0.231
3 1/2	3.42	1.03	2.39	0.604	4.000	0.248	4.843	5.09[2]		1.250	4.00	3.24	1.90	...	...	...	3.43	0.248
4	3.79	1.08	2.61	0.661	4.500	0.265	5.401	5.69	3.70	1.300	4.38	3.70	2.08	2.01	6.97	8.98	3.69	0.265
5	4.50	1.18	3.05	0.780	5.563	0.300	6.583	6.86[2]	..	1.406	5.12	4.69	2.32	....	..	...	..	0.300
6	5.13	1.28	3.46	0.900	6.625	0.336	7.767	8.03[2]	...	1.513	5.86	5.67	2.55	...	....	....	....	0.336

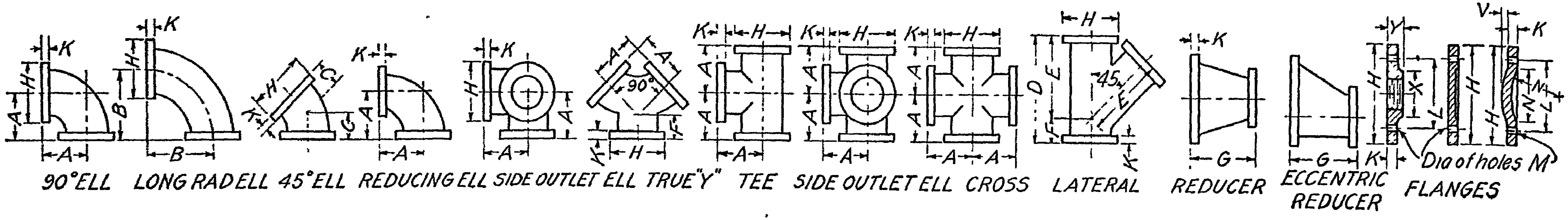
Dimensions in inches.

Left-hand couplings have four or more ribs. Right-hand couplings have two ribs.

[1] ASA B16c 1939.

Street tee not made in 1/8″ size.

[2] Street ell only.



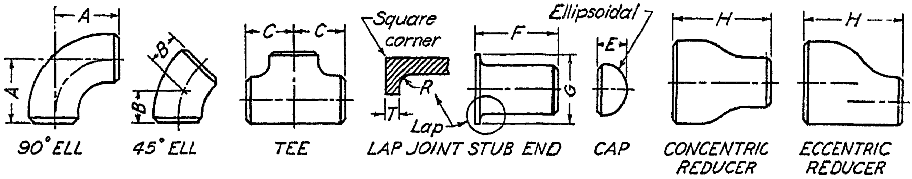
American Standard Cast-iron Pipe Flanges and Flanged Fittings[1]
For Maximum Working Saturated Steam Pressure of 125 Lb. per Sq. In. (Gage)
Approved by American Standards Association, 1939

Nominal pipe size N	A	B	C	D	E	F	G	H	K min.	L	M	Number of bolts	Dia. of bolts	Length of bolts	X min.	Y min.	Wall thickness	V
1	3 1/2	5	1 3/4	7 1/2	5 3/4	1 3/4	....	4 1/4	7/16	3 1/8	5/8	4	1/2	1 3/4	1 15/16	1 1/16	5/16	3/8
1 1/4	3 3/4	5 1/2	2	8	6 1/4	1 3/4	....	4 5/8	1/2	3 1/2	5/8	4	1/2	2	2 5/16	1 3/16	5/16	7/16
1 1/2	4	6	2 1/4	9	7	2	....	5	9/16	3 7/8	5/8	4	1/2	2	2 9/16	7/8	5/16	1/2
2	4 1/2	6 1/2	2 1/2	10 1/2	8	2 1/2	5	6	5/8	4 3/4	3/4	4	5/8	2 1/4	3 1/16	1	5/16	9/16
2 1/2	5	7	3	12	9 1/2	2 1/2	5 1/2	7	11/16	5 1/2	3/4	4	5/8	2 1/2	3 9/16	1 1/8	5/16	5/8
3	5 1/2	7 3/4	3	13	10	3	6	7 1/2	3/4	6	3/4	4	5/8	2 1/2	4 1/4	1 3/16	3/8	11/16
3 1/2	6	8 1/2	3 1/2	14 1/2	11 1/2	3	6 1/2	8 1/2	13/16	7	3/4	8	5/8	2 3/4	4 13/16	1 1/4	7/16	3/4
4	6 1/2	9	4	15	12	3	7	9	15/16	7 1/2	3/4	8	5/8	3	5 5/16	1 5/16	1/2	7/8
5	7 1/2	10 1/4	4 1/2	17	13 1/2	3 1/2	8	10	15/16	8 1/2	7/8	8	3/4	3	6 7/16	1 7/16	1/2	7/8
6	8	11 1/2	5	18	14 1/2	3 1/2	9	11	1	9 1/2	7/8	8	3/4	3 1/4	7 9/16	1 9/16	9/16	15/16
8	9	14	5 1/2	22	17 1/2	4 1/2	11	13 1/2	1 1/8	11 3/4	7/8	8	3/4	3 1/2	9 11/16	1 3/4	5/8	1 1/16
10	11	16 1/2	6 1/2	25 1/2	20 1/2	5	12	16	1 3/16	14 1/4	1	12	7/8	3 3/4	11 15/16	1 15/16	3/4	1 1/8
12	12	19	7 1/2	30	24 1/2	5 1/2	14	19	1 1/4	17	1	12	7/8	3 3/4	14 1/16	2 3/16	13/16	

Dimensions in inches.

[1] ASA B16a 1939.

American Standard Steel Butt-welding Fittings[1,2]



ELBOWS, TEES, CAPS AND STUB ENDS

Nominal pipe size	Outside diameter at bevel	Center to end: 90-deg. welding elbow, *A*	Center to end: 45-deg. welding elbow, *B*	Center to end: of run, welding tee, *C*	Welding caps, *E*	Lapped-joint stub ends: Lengths, *F*	Lapped-joint stub ends: Radius of fillet, *R*	Lapped-joint stub ends: Diameter of lap, *G*
1	0.310	1½	⅞	1½	1½	4	⅛	2
1¼	1.660	1⅞	1	1⅞	1½	4	3/16	2½
1½	1.900	2¼	1⅛	2¼	1½	4	¼	2⅞
2	2 375	3	1⅜	2½	1½	6	5/16	3⅝
2½	2.875	3¾	1¾	3	1½	6	5/16	4⅛
3	3.500	4½	2	3⅜	2	6	⅜	5
3½	4.000	5¼	2¼	3¾	2½	6	⅜	5½
4	4.500	6	2½	4⅛	2½	6	7/16	6 3/16

BUTT-WELDING REDUCERS

Nominal pipe size	Outside diameter at bevel: Large end	Outside diameter at bevel: Small end	End to end, *H*
1 × ¾	1.315	1.050	2
1 × ½		0.840	
1 × ⅜		0.675	
1¼ × 1	1.660	1.315	2
1¼ × ¾		1.050	
1¼ × ½		0.840	
1½ × 1¼	1.900	1.660	2½
1½ × 1		1.315	
1½ × ¾		1.050	
1½ × ½		0.840	
2 × 1½	2.375	1.900	3
2 × 1¼		1.660	
2 × 1		1.315	
2 × ¾		1.050	
2½ × 2	2.875	2.375	3½
2½ × 1½		1.900	
2½ × 1¼		1.660	
2½ × 1		1.315	

Nominal pipe size	Outside diameter at bevel: Large end	Outside diameter at bevel: Small end	End to end, *H*
3 × 2½	3.500	2.875	3½
3 × 2		2.375	
3 × 1½		1.900	
3 × 1¼		1.660	
3½ × 3	4.000	3.500	4
3½ × 2½		2.875	
3½ × 2		2.375	
3½ × 1½		1.900	
3½ × 1¼		1.660	
4 × 3½	4.500	4 000	4
4 × 3		3.500	
4 × 2½		2.875	
4 × 2		2.375	
4 × 1½		1.900	
5 × 4	5.563	4.500	5
5 × 3½		4.000	
5 × 3		3.500	
5 × 2½		2.875	

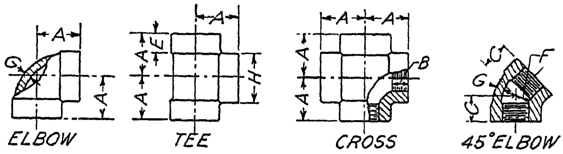
Dimensions in inches.

[1] For larger sizes see ASA B16.

[2] ASA B16.9 1940.

American Standard Cast-iron Screwed Fittings[1]

For Maximum Working Saturated Steam Pressure of 125 and 250 Lb. per Sq. In.

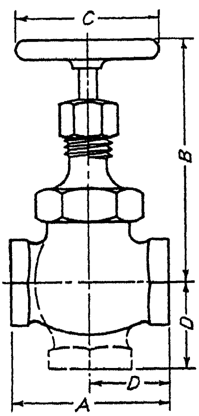


Nominal pipe size	A	B	C	E	F		G	H
		min.		min.	Min.	Max.	min.	min.
¼	0.81	0.32	0.73	0.38	0.540	0.584	0.110	0.93
⅜	0.95	0.36	0.80	0.44	0.675	0.719	0.120	1.12
½	1.12	0.43	0.88	0.50	0.840	0.897	0.130	1.34
¾	1.31	0.50	0.98	0.56	1.050	1.107	0.155	1.63
1	1.50	0.58	1.12	0.62	1.315	1.385	0.170	1.95
1¼	1.75	0.67	1.29	0.69	1.660	1.730	0.185	2.39
1½	1.94	0.70	1.43	0.75	1.900	1.970	0.200	2.68
2	2.25	0.75	1.68	0.84	2.375	2.445	0.220	3.28
2½	2.70	0.92	1.95	0.94	2.875	2.975	0.240	3.86
3	3.08	0.98	2.17	1.00	3.500	3.600	0.260	4.62
3½	3.42	1.03	2.39	1.06	4.000	4.100	0.280	5.20
4	3.79	1.08	2.61	1.12	4.500	4.600	0.310	5.79
5	4.50	1.18	3.05	1.18	5.563	5.663	0.380	7.05
6	5.13	1.28	3.46	1.28	6.625	6.725	0.430	8.28
8	6.56	1.47	4.28	1.47	8.625	8.725	0.550	10.63
10	8.08	1.68	5.16	1.68	10.750	10.850	0.690	13.12
12	9.50	1.88	5.97	1.88	12.750	12.850	0.800	15.47

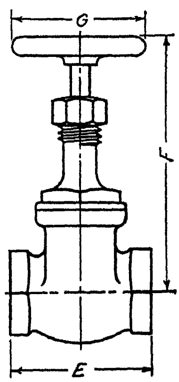
Dimensions in inches.

[1] ASA B16d 1941.

Globe, Angle-globe and Gate Valves[1]



Size	A	B (open)	C	D	E	F (open)	G
⅛	2	4	1¾	1	...	....	...
¼	2	4	1¾	1	1⅞	5⅛	1¾
⅜	2¼	4½	2	1⅛	2	5⅛	1¾
½	2¾	5¼	2½	1¼	2⅛	5½	2
¾	3 3/16	6	2¾	1½	2⅜	6⅝	2½
1	3¾	6¾	3	1¾	2⅞	7⅞	2¾
1¼	4¼	7¼	3⅝	2	3¼	9½	3
1½	4¾	8¼	4	2¼	3½	10⅞	3⅝
2	5¾	9½	4¾	2¾	3⅞	13⅛	4
2½	6¾	11	6	3¼	4½	15⅜	4¾
3	8	12¼	7	3¾	5	17⅞	5⅜



Dimensions in inches.

[1] Dimensions compiled from manufacturers' catalogues for drawing purposes.

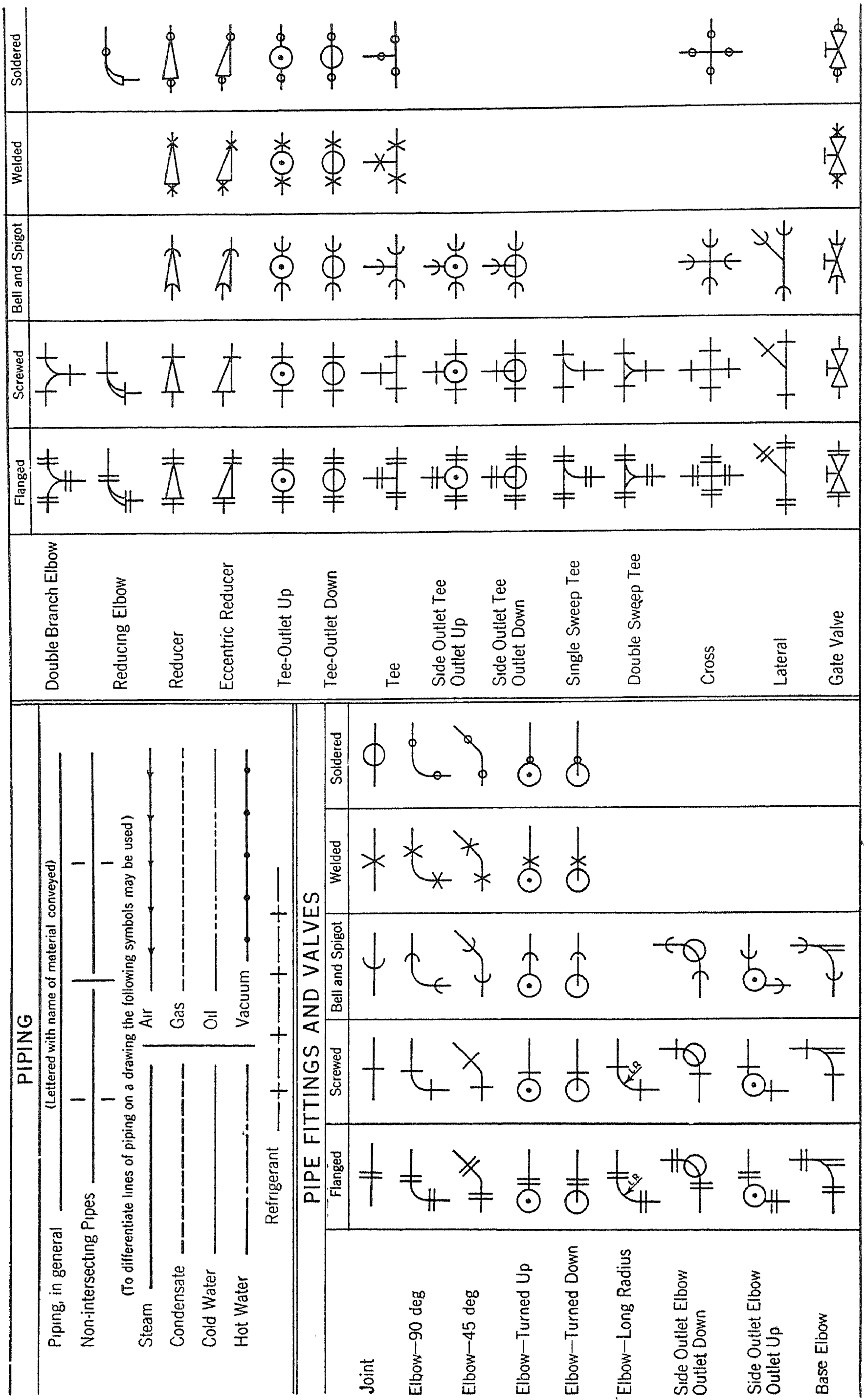


FIG. 1051.—American Standard graphical symbols. ASA Z14.2 1935.

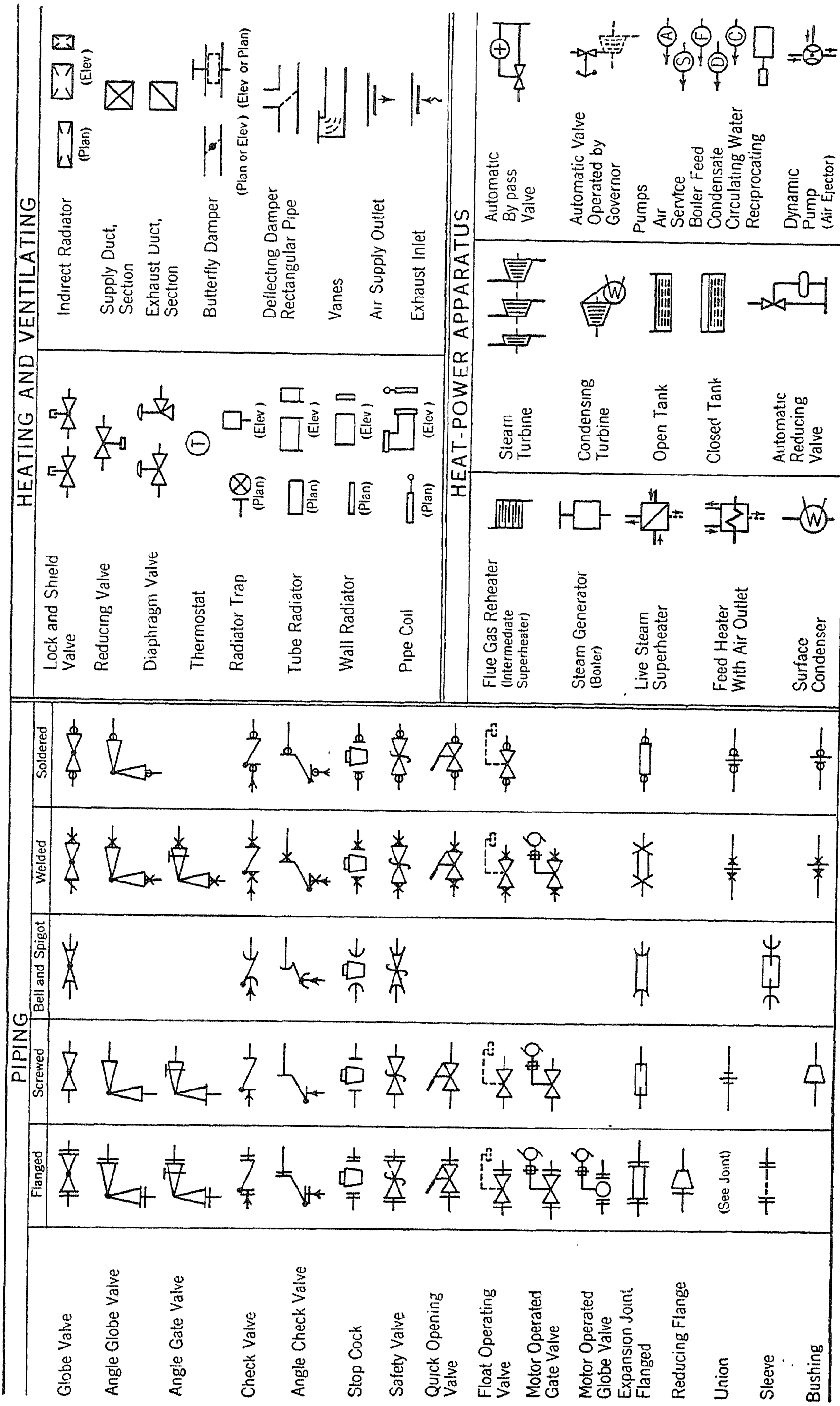


FIG. 1052.—American Standard graphical symbols. ASA Z14.2 1935.

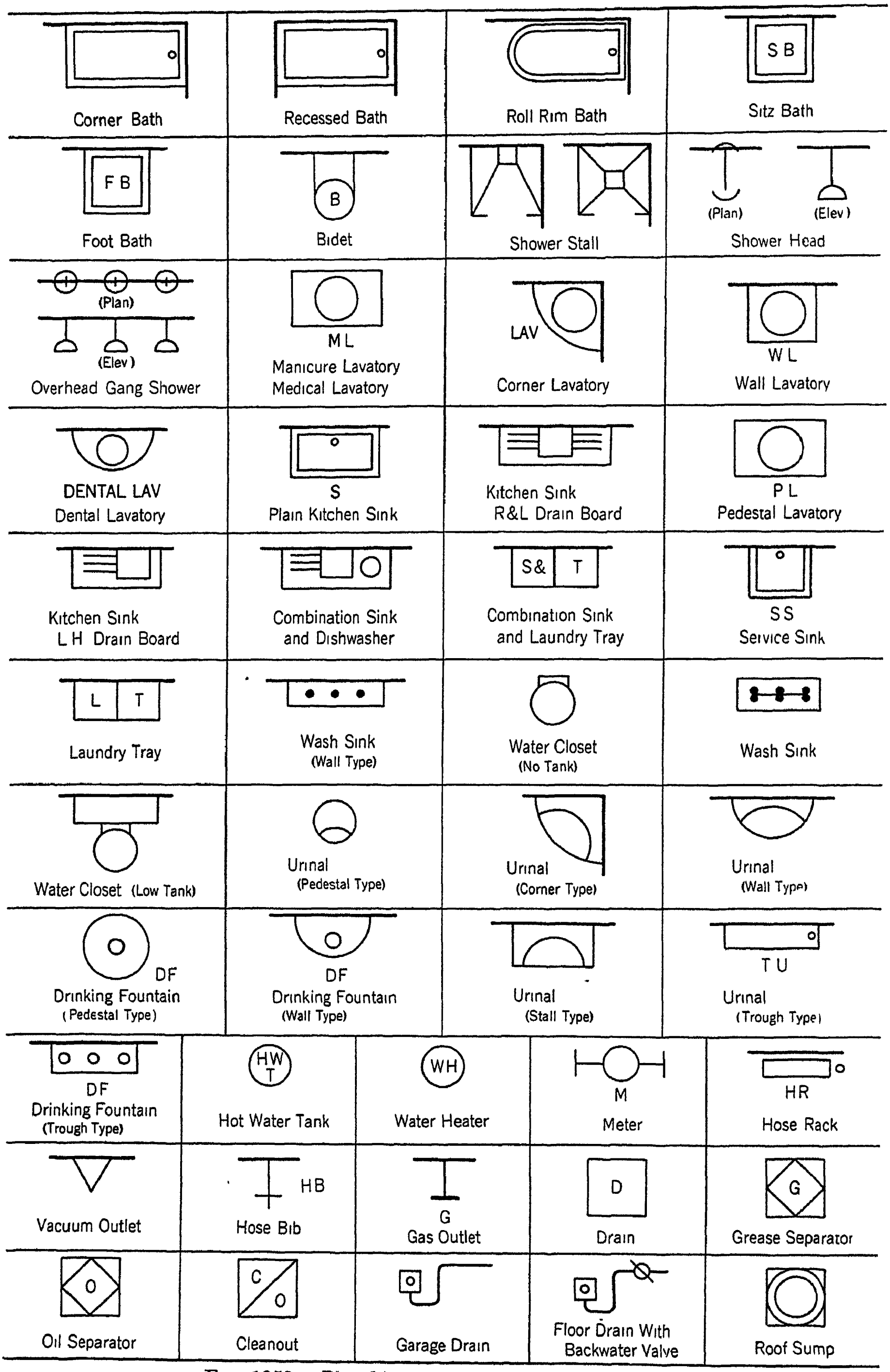


FIG. 1053.—Plumbing symbols. ASA Z14.2 1935.

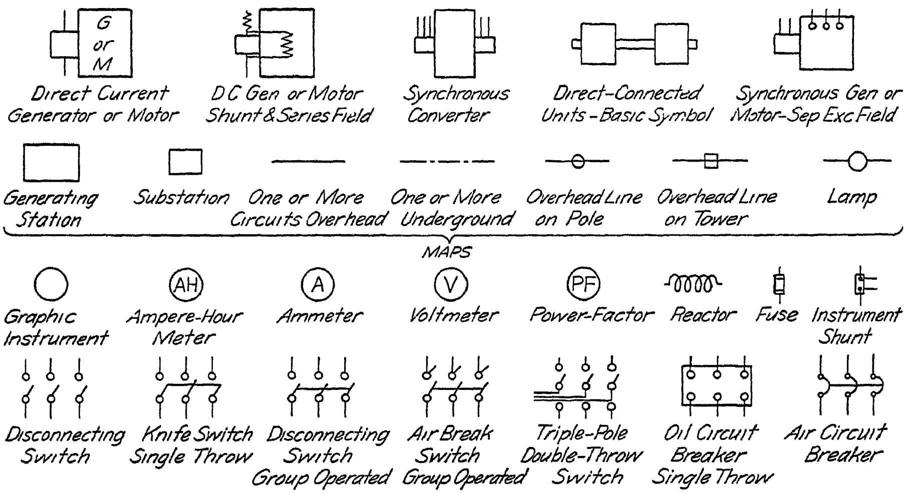


FIG. 1054.—Electric symbols. ASA Z10g2 1934.

Electric Symbols.—Symbols for the diagrammatic representation of electric apparatus and construction have not been full standardized. Figure 1054 gives the basic symbols which are in general use in electrical drawing.

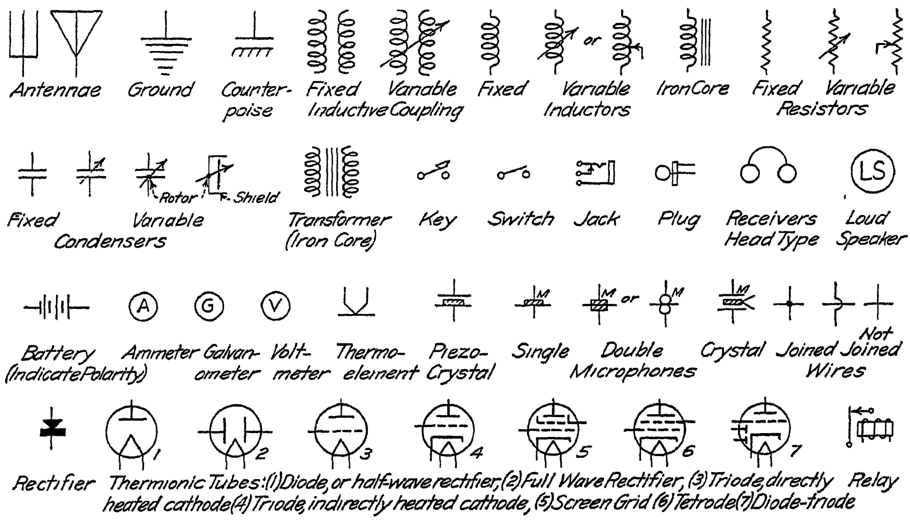


FIG. 1055.—Radio symbols. ASA Z10g3 1933.

Radio Symbols.—Figure 1055 gives the radio symbols in present general use. Most of these are approved as American Tentative Standard but certain symbols have not yet been approved because of conflicts with those for the same device as used in the electric-power and electric-traction fields.

For patent drawings the set of symbols specified in the "Rules of Practice" should be followed.

The American Standard wiring symbols, Fig. 1056, are in universal use by architects and electricians.

Ceiling Outlet
" " for Extensions E
" Lamp Receptacle, Specifications to describe type, as Key, Keyless or Pull Chain R
Ceiling Fan Outlet
Pull Switch PS
Drop Cord D
Wall Bracket
" Outlet for Extensions E
" Lamp Receptacle, as specified R
" Fan Outlet
Single Convenience Outlet
Double " " " 2
Junction Box J
Special Purpose Outlets Lighting, Heating and Power as described in specifications
Exit Light
Floor Outlet
Floor Elbow E, Floor Tee T
Local Switch, Single Pole S^1
Double Pole S^2, 3-Way S^3, 4-Way S^4
Automatic Door Switch S^D
Key Push Button Switch S^K
Electrolier Switch S^E
Push Button Switch and Pilot S^P
Remote Control Push Button Switch S^R
Tank Switch T.S.
Motor, Motor Controller M.C.
Lighting Panel
Power Panel
Heating Panel
Pull Box
Cable Supporting Box
Meter
Transformer
Push Button
Pole Line
Buzzer, Bell

Branch Circuit, Run Exposed
Run Concealed Under Floor
" " " Floor Above
Feeder Run Exposed
Run Concealed Under Floor
" " " Floor Above
Telephone, Interior, Public
Clock, Secondary, Master
Time Stamp
Electric Door Opener
Local Fire Alarm Gong F
City Fire Alarm Station
Local " " " F
Fire Alarm Central Station FA
Speaking Tube
Nurse's Signal Plug N
Maid's Plug M
Horn Outlet
District Messenger Call
Watchman Station W
Watchman Central Station Detector W
Public Telephone-P.B.X. Switchboard PB
Interior Telephone Central Switchboard IX
Interconnection Cabinet
Telephone Cabinet
Telegraph "
Special Outlet for Signal System as Specified
Battery
Signal Wires in Conduit Under Floor
" " " " " Floor Above
This Character Marked on Tap Circuits Indicates
2 No. 14 Conductors in $\frac{1}{2}''$ Conduit ||
3 " 14 " " $\frac{1}{2}''$ " |||
4 " 14 " " $\frac{3}{4}''$ " (Unless Marked $\frac{1}{2}''$) ||||
5 " 14 " " $\frac{3}{4}''$ " |||||
6 " 14 " " 1" " (Unless Marked $\frac{3}{4}''$) ||||||
7 " 14 " " 1" " |||||||
8 " 14 " " 1" " ||||||||
(Radio Outlet)

Wire and Sheet-metal Gages

Dimensions in Decimal Parts of an Inch

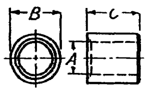
Number of gage	American or Brown and Sharpe[1]	Washburn & Moen or American Steel & Wire Co.[2]	Birmingham or Stubs iron wire[3]	Music wire[4]	Twist-drill sizes[5]	Imperial wire gage[6]	U.S. Std. for plate[7]	Number of gage
0000000	.....	0.4900	....	.....	......	0.5000	0.5000	0000000
000000	0.5800	0.4615	...	0.004	......	0.4640	0.4688	000000
00000	0.5165	0.4305	0.500	0.005	.....	0.4320	0.4375	00000
0000	0.4600	0.3938	0.454	0.006	.....	0.4000	0.4063	0000
000	0.4096	0.3625	0.425	0.007	......	0.3720	0.3750	000
00	0.3648	0.3310	0.380	0.008	......	0.3480	0.3438	00
0	0.3249	0.3065	0.340	0.009	.....	0.3240	0.3125	0
1	0.2893	0.2830	0.300	0.010	0.2280	0.3000	0.2813	1
2	0.2576	0.2625	0.284	0.011	0.2210	0.2760	0.2656	2
3	0.2294	0.2437	0.259	0.012	0.2130	0.2520	0.2500	3
4	0.2043	0.2253	0.238	0.013	0.2090	0.2320	0.2344	4
5	0.1819	0.2070	0.220	0.014	0.2055	0.2120	0.2188	5
6	0.1620	0.1920	0.203	0.016	0.2040	0.1920	0.2031	6
7	0.1443	0.1770	0.180	0.018	0.2010	0.1760	0.1875	7
8	0.1285	0.1620	0.165	0.020	0.1990	0.1600	0.1719	8
9	0.1144	0.1483	0.148	0.022	0.1960	0.1440	0.1563	9
10	0.1019	0.1350	0.134	0.024	0.1935	0.1280	0.1406	10
11	0.0907	0.1205	0.120	0.026	0.1910	0.1160	0.1250	11
12	0.0808	0.1055	0.109	0.029	0.1890	0.1040	0.1094	12
13	0.0720	0.0915	0.095	0.031	0.1850	0.0920	0.0938	13
14	0.0641	0.0800	0.083	0.033	0.1820	0.0800	0.0781	14
15	0.0571	0.0720	0.072	0.035	0.1800	0.0720	0.0703	15
16	0.0508	0.0625	0.065	0.037	0.1770	0.0640	0.0625	16
17	0.0453	0.0540	0.058	0.039	0.1730	0.0560	0.0563	17
18	0.0403	0.0475	0.049	0.041	0.1695	0.0480	0.0500	18
19	0.0359	0.0410	0.042	0.043	0.1660	0.0400	0.0438	19
20	0.0320	0.0348	0.035	0.045	0.1610	0.0360	0.0375	20
21	0.0285	0.0317	0.032	0.047	0.1590	0.0320	0.0344	21
22	0.0253	0.0286	0.028	0.049	0.1570	0.0280	0.0313	22
23	0.0226	0.0258	0.025	0.051	0.1540	0.0240	0.0281	23
24	0.0201	0.0230	0.022	0.055	0.1520	0.0220	0.0250	24
25	0.0179	0.0204	0.020	0.059	0.1495	0.0200	0.0219	25
26	0.0159	0.0181	0.018	0.063	0.1470	0.0180	0.0188	26
27	0.0142	0.0173	0.016	0.067	0.1440	0.0164	0.0172	27
28	0.0126	0.0162	0.014	0.071	0.1405	0.0148	0.0156	28
29	0.0113	0.0150	0.013	0.075	0.1360	0.0136	0.0141	29
30	0.0100	0.0140	0.012	0.080	0.1285	0.0124	0.0125	30
31	0.0089	0.0132	0.010	0.085	0.1200	0.0116	0.0109	31
32	0.0080	0.0128	0.009	0.090	0.1160	0.0108	0.0102	32
33	0.0071	0.0118	0.008	0.095	0.1130	0.0100	0.0094	33
34	0.0063	0.0104	0.007	0.100	0.1110	0.0092	0.0086	34
35	0.0056	0.0095	0.005	0.106	0.1100	0.0084	0.0078	35
36	0.0050	0.0090	0.004	0.112	0.1065	0.0076	0.0070	36
37	0.0045	0.0085	.....	0.118	0.1040	0.0068	0.0066	37
38	0.0040	0.0080	.....	0.124	0.1015	0.0060	0.0063	38
39	0.0035	0.0075	.....	0.130	0.0995	0.0052	......	39
40	0.0031	0.0070	.....	0.138	0.0980	0.0048	......	40

[1] Recognized standard in the United States for wire and sheet metal of copper and other metals except steel and iron.
[2] Recognized standard for steel and iron wire. Called the "U.S. steel wire gage."
[3] Formerly much used, now nearly obsolete.
[4] American Steel & Wire Company's music or piano wire gage. Recommended by U.S. Bureau of Standards.
[5] Known as the "Manufacturers' Standard."
[6] Official British Standard.
[7] Legalized U.S. Standard for iron and steel plate, although plate is now always specified by its thickness in decimals of an inch.

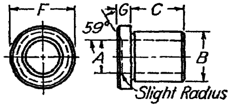
A committee of the American Standards Association is at present working on the "standardization of a method of designating the diameter of metal and metal-alloy wire . . . and the establishment of standard series of nominal sizes . . . "

Preferred thicknesses for uncoated thin flat metals (under 0.250 in.), ASA B32, 1941, gives recommended sizes for sheets.

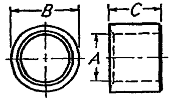
ASA Standard Jig Bushings B5.6 1935



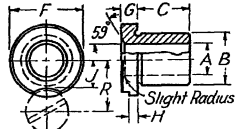
AIN PRESS FIT
Type "P"



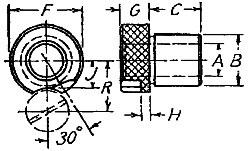
SHOULDER PRESS FIT
Type "S"



LINER - Type "L"
Note Length "C" same as corresponding bushing



REPLACEABLE STATIONARY
Type "RS"



REMOVABLE SLIP
Type "R"

TYPES P AND S

Group	Drill sizes A	Nominal outside diameter bushing B	Length under head C	Symbol	Head diameter type S F	Head diameter type S G
1	54–39	13/64	5/16 1/2	11 12	5/16	3/32
2	38–29	1/4	5/16 1/2	21 22	3/8	3/32
3	28–3/16	5/16	5/16 1/2 3/4 1	31 32 33 34	7/16	1/8
04	12–1/4	13/32	5/16 1/2 3/4 1 1 3/8 1 3/4	041 042 043 044 045 046	9/16	5/32
4	F–5/16	1/2	5/16 1/2 3/4 1 1 3/8 1 3/4	41 42 43 44 45 46	5/8	7/32

TYPES RS AND R

Group	Drill sizes A	Nominal outside diameter bushing B	Nominal outside diameters liners only B
3	54–43 3/32–5/32	5/16	1/2
4	22–5/16	1/2	3/4

TYPES P, S, RS AND R

Group	Drill sizes A	Nominal outside diameter bushing B	Length under head C	Symbol	Head diameter type S F	Head diameter type S G	Nominal outside diameters, liners only B
7	49/64–1	1 3/8	3/4 1 1 3/8 1 3/4 2 1/8 2 1/2	73 74 75 76 77 78	1 5/8	3/8	1 3/4
8	1 1/64–1 3/8	1 3/4	1 1 3/8 1 3/4 2 1/8 2 1/2 3	84 85 86 87 88 89	2	3/8	2 1/4
9	1 25/64–1 3/4	2 1/4	1 1 3/8 1 3/4 2 1/8 2 1/2 3	94 95 96 97 98 99	2 1/2	3/8	2 3/4

Dimensions in inches.

Group	Head dimensions									
	Type RS					Type R				
	F	G	H	J	R	F	G	H	J	R
3	9/16	1/4	1/8	11/64	1/2	9/16	3/8	1/8	11/64	1/2
	Use Lock Screw No. 1A									
4	13/16	1/4	1/8	19/64	5/8	13/16	7/16	1/8	19/64	5/8
	Use Lock Screw No. 1A									
5	1 1/16	1/4	1/8	27/64	3/4	1 1/16	7/16	1/8	27/64	3/4
	Use Lock Screw No. 1A									
6	1 7/16	3/8	3/16	19/32	59/64	1 7/16	7/16	3/16	19/32	59/64
	Use Lock Screw No. 2A									
7	1 13/16	3/8	3/16	25/32	1 7/64	1 13/16	7/16	3/16	25/32	1 7/64
	Use Lock Screw No. 2A									
8	2 5/16	3/8	3/16	1	1 25/64	2 5/16	5/8	3/16	1	1 25/64
	Use Lock Screw No 3A									
9	2 13/16	3/8	3/16	1 1/4	1 41/64	2 13/16	5/8	3/16	1 1/4	1 41/64
	Use Lock Screw No. 3A									

ASA Standard Jig Bushings.—(*Continued*)

TYPES P AND S / TYPES RS AND R

Group	Drill sizes A	Nominal outside diameter bushing B	Length under head C	Symbol	Head diameter type S F	Head diameter type S G	Group	Drill sizes A	Nominal outside diameter bushing B	Length under head C
05	0–27/64	5/8	1/2	052	3/16	7/32				
			3/4	053						
			1	054						
			1 3/8	055						
			1 3/4	056						
			2 1/8	057						
5	7/16–1/2	3/4	1/2	52	15/16	7/32	5	0–1/2	3/4	1
			3/4	53						
			1	54						
			1 3/8	55						
			1 3/4	56						
			2 1/8	57						
06	33/64–5/8	7/8	3/4	063	1 1/16	1/4				
			1	064						
			1 3/8	065						
			1 3/4	066						
			2 1/8	067						
			2 1/2	068						
6	41/64–3/4	1	3/4	63	1 1/4	5/16	6	33/64–3/4	1	1 3/8
			1	64						
			1 3/8	65						
			1 3/4	66						
			2 1/8	67						
			2 1/2	68						

Dimensions in inches.

DRILL CLEARANCE FOR ALL BUSHINGS EXCEPT LINERS

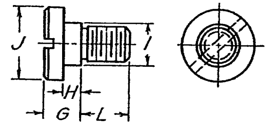
Group	Min.	Max.
1, 2, 3, 04, 4 (to 1/4" drill)	+0 0001	+0 0004
4 (above 1/4" drill), 05, 5, 06, 6	+0 0001	+0 0005
7, 8, 9 (to 1 1/2" drill) . .	+0 0002	+0 0006
9 (above 1 1/2" drill) . . .	+0.0003	+0 0007

LINERS

Group	Inside diameter Min.	Inside diameter Max.	Outside diameter Min.	Outside diameter Max.
3	0.3126	0 3129	0.5014	0.5017
4	0.5002	0 5005	0.7515	0.7518
5	0.7503	0 7506	1.0015	1 0018
6	1.0004	1.0007	1 3768	1 3772
7	1.3756	1.3760	1.7519	1.7523
8	1 7508	1.7512	2.2521	2 2525
9	2.2510	2.2515	2.7522	2.7526

To specify a bushing, give the type and symbol number followed by the drill size.
Example:
ASA *XP* – 63 for 41/64 Drill.

LOCK SCREW



Group Nos.	Screw No.	G	H	I	J	L	ASA th'd
3–5	1A	1/4	1/8	3/8	5/8	3/8	5/16–18
6–7	2A	3/8	3/16	3/8	5/8	3/8	5/16–18
8–9	3A	3/8	3/16	7/16	3/4	1/2	3/8–16

SLIP-FIT BUSHINGS—O. D.

Group	Minimum	Maximum
3	0 3123	0.3125
4	0.4998	0.5000
5	0 7498	0.7500
6	0.9998	1.0000
7	1 3747	1 3750
8	1.7497	1.7500
9	2 2496	2 2500

PRESS FIT BUSHINGS—O. D.

Group	Minimum	Maximum
1	0 2043	0 2046
2	0.2513	0 2516
3	0 3138	0.3141
04	0 4075	0.4078
4	0 5014	0 5017
05	0.6264	0 6267
5	0.7515	0 7518
06	0.8765	0 8768
6	1.0015	1 0018
7	1.3768	1.3772
8	1 7519	1 7523
9	2 2521	2 2525

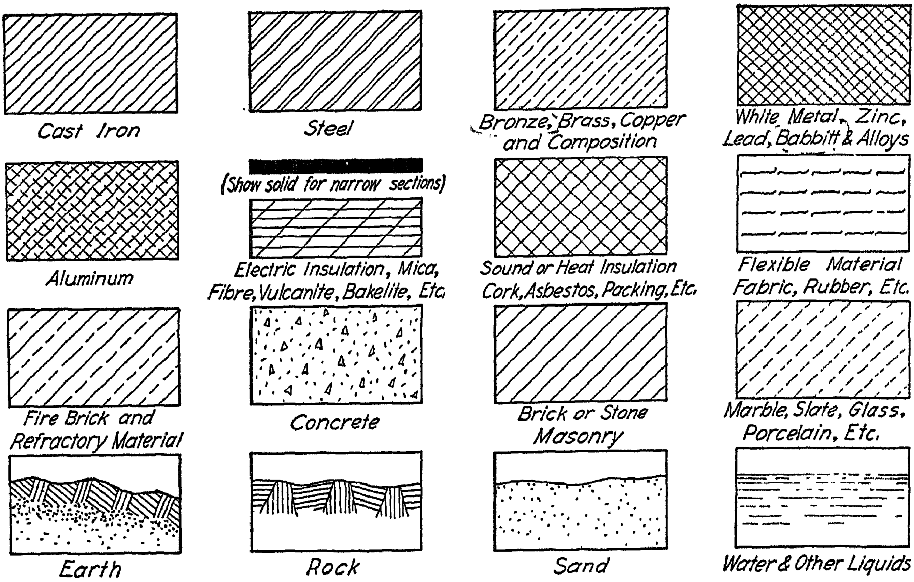


FIG. 1057.—Symbols for materials in section.

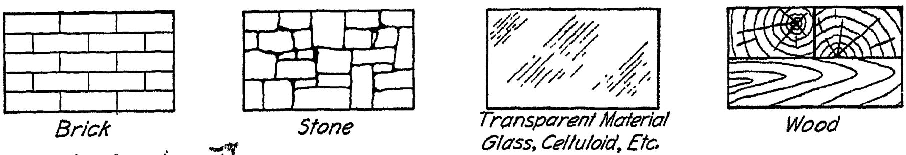


FIG. 1058.—Symbols for materials, exterior.

Symbols for Colors.—Line symbols for the indication of colors were first used in heraldry, at the time that it became necessary to draw a coat-of-arms in black and white instead of in the full color of the achievement. This is an artistic improvement over the older method of indicating the different colors by "tricking," that is, putting the initials of the colors on the various spaces. The heraldic names of the colors are *gules*—red, *azure*—blue, *vert*—green, *purpure*—purple, *sable*—black, *tenny*—tawny, *sanguine*—dark red, *argent*—silver and *or*—gold, all of which are represented by line or dot symbols. These heraldic symbols have become the universal standard in all kinds of drawing when colors have to be symbolized or specified, as might occur in indicating the required colors of a fabric or design, such as the device illustrated in Fig. 60. This is notably true in patent-office drawing, as mentioned on page 549, where the arrangement of color may be an essential part of a design patent. The symbols of Fig. 1059 are the patent-office standards, and, with the exception of orange, are also those used in heraldry.

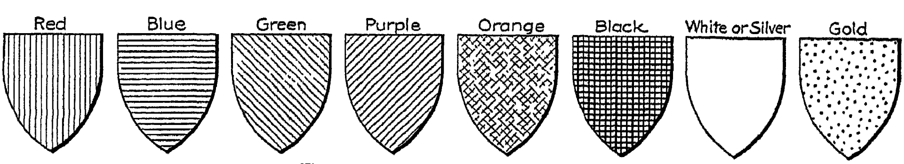


FIG. 1059.—Symbols for colors.

ABBREVIATIONS AND WORD SYMBOLS TO BE USED ON DRAWINGS

Alternating current	a-c
Angle (structural shape)	∟
American Standard	Am Std
American Standards Association	ASA
American wire gage (B & S gage)	Awg
Approved (by)	App
Ball bearing	bb
Birmingham wire gage	Bwg
Brown & Sharpe gage	B & S
Babbitt metal (specified by number)	bab #——
Brass, SAE (specified by number)	br #——
Bronze, SAE (specified by number)	bro #——
Brinell hardness number	Bhn
Cast iron	CI
Center line	℄ or CL
Center to center	c to c
Centimeter (s)	cm
Chamfer	chfr
Channel	⊔
Checked (by)	Ch
Circular	cir
Circular pitch (gear drawings)	CP
Copper	cop
Cold rolled steel	CRS
Counterbore	c'bore
Countersink	csk
Cubic inches (feet; yards)	cu in (ft; yds)
Cylinder, cylindrical	cyl
Degree (s) (angular measurement)	° or deg
Diameter	D
Direct current	d-c
Diagonal	diag
Diametral pitch (gear drawings)	DP
Drawing (s)	Dwg, Dwgs
Drawn (by)	Dr
Drop forging	D forg
Detail drawing	Dtl dwg
Die casting	D cast
Die stamping	D st
External	ext
Extra fine (Am Std fine thread)	EF
Fabricate	fab
Fillister	fil
Foot, Feet	ft or ′
Finish	V or fin or f
Gage	ga
Gallon	gal
Galvanized iron	GI
Grind	gr
H Beam	H
Head	hd
Hexagonal	hex
Harden	hdn
Horsepower	hp or HP
Heat-treatment, SAE (specified by number)	htr #——
I beam	I
Impregnate	impreg
Inside diameter	ID
Inch (es)	″ or in
Insulate, insulated	insl
Kilowatt	kw
Kip	k
Left hand	LH
Laminate	lam
Lateral	lat
Longitudinal	long
Lubricate, lubrication	lub
Machine	mach
Magnetic	mag
Malleable iron	Mal I
Maximum	max
Meter (s)	m
Millimeter (s)	mm
Minute (s), (time)	′ or min
Minute (s) (angular measure)	′
Minimum	min
National form (screw threads)	N
National Coarse (screw threads)	NC
National Fine (screw threads)	NF
National Electrical Code	NEC
Number	# or no
On center—(center to center)	oc
Outside diameter	OD

Oxidize	ox
Parallel to	‖
Patent	pat
Pattern	patt
Perforate	perf
Perpendicular to	⊥
Phosphor bronze	phos bro
Piece (s)	pc, pcs
Pitch	P
Pitch diameter	PD
Plate	pl
Pound	# or lb
Pratt and Whitney (key)	P & W
Propeller	prop
Quart	qt
Radius	R
Required	req
Revolutions per minute	rpm
Revolutions per second	rps
Right hand	RH
Round	rd
Round bar	⏀
Round bar deformed	⏀̸
Screw	sc
Section	sec
Society of Automotive Engineers	SAE
Square	□ or sq
Square bar	⌷
Square bar, deformed	⌷̸
Square foot, feet	sq ft or □′
Square inch (es)	sq in or □″
Standard	Std
Steel	Stl
Steel casting	Stl C
Tee (structural shape)	T
Teeth (on gear drawings)	T
Thread (s)	thd, thds
Traced (by)	Tr
United States form (old)	USF
United States Standard (old)	USS
Wide flange section (structural)	WF
Woodruff (key)	spell out or Wdrf
Wrought iron	WI
Yard (s)	yd, yds
Zee (structural shape)	Z

THE GREEK ALPHABET

While Greek is not a required study in most engineering curricula, the engineer often uses letters of the Greek alphabet, both capitals and lower case, as symbols and reference letters. He should therefore be able to draw them readily and to read them without hesitation when encountered in equations or formulas.

There is a variety in Greek alphabets, just as there is in Roman alphabets. The one given below is a legible form with accented and unaccented strokes in the capitals that follow closely the rules for shading Roman letters. The lower case has good historical precedent in form,shading and comparative size.

Fig. 1060.—Alphabet of Greek capitals and lower-case letters.

Weights of Materials

Commercial bronze, 95 per cent	0.320 lb/cu in	Steel, tool	0.272 lb/cu in
Commercial bronze, 90 per cent	0.318 lb/cu in	Tin	0.263 lb/cu in
Red brass, 85 per cent	0.316 lb/cu in	Zinc	0.254 lb/cu in
Red brass, 80 per cent	0.313 lb/cu in	Glass, common	0.094 lb/cu in
Drawing or spinning brass	0.306 lb/cu in	Glass, plate	0.093 lb/cu in
Muntz metal	0.303 lb/cu in	Duralumin	0.103 lb/cu in
Tobin bronze	0.304 lb/cu in	Copper	0.318 lb/cu in
Everdur	0.308 lb/cu in	Gold	0.697 lb/cu in
Cast aluminum SAE No. 30	0.102 lb/cu in	Silver	0.380 lb/cu in
Cast aluminum SAE No. 321	0.097 lb/cu in	Water	62.4 lb/cu ft
Iron, gray cast	0.260 lb/cu in	Sandstone	144.0 lb/cu ft
Iron, wrought	0.283 lb/cu in	Limestone	163.0 lb/cu ft
Babbitt metal	0.267 lb/cu in	Fire brick	17.5 lb/cu ft
Aluminum	0.092 lb/sq in	Cypress	30.0 lb/cu ft
Lead	0.411 lb/cu in	Maple (hard)	33.0 lb/cu ft
Mercury	0.490 lb/cu in	Pine (yellow, long leaf)	44.0 lb/cu ft
Nickel	0.318 lb/cu in	Pine (white)	26.0 lb/cu ft
Monel metal	0.322 lb/cu in	Oak (white)	46.0 lb/cu ft
Steel, cold drawn	0.283 lb/cu in	Redwood	26.0 lb/cu ft
Steel, machine steel	0.282 lb/cu in	African teak	62.0 lb/cu ft

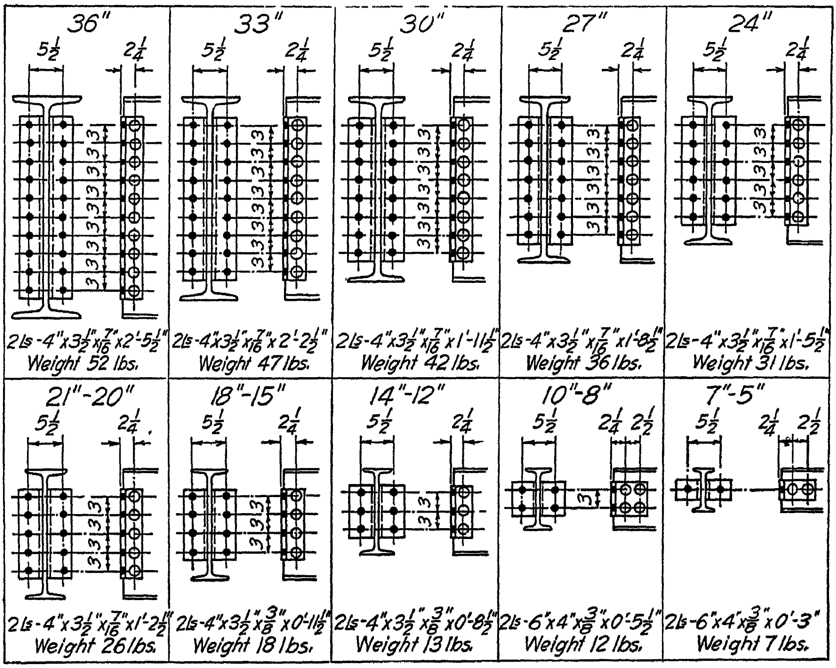


Fig. 1061.—Beam connections.

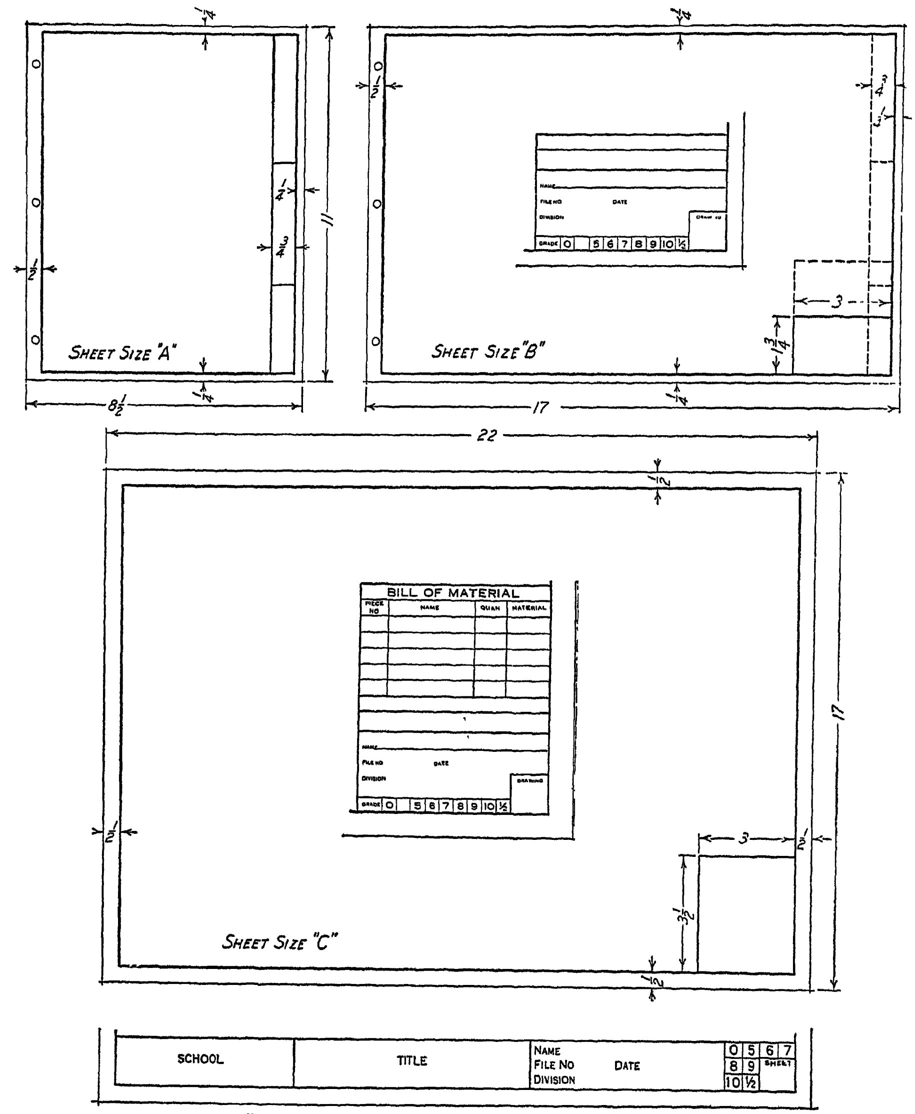


FIG. 1062.—American Standard sheet sizes.

The American Standard trimmed sizes of drawing paper and cloth are as follows: A, $8\frac{1}{2}'' \times 11''$; B, $11'' \times 17''$; C, $17'' \times 22''$; D, $22'' \times 34''$; and E, $34'' \times 44''$. These sizes are based on the dimensions of the commercial letterhead, $8\frac{1}{2}'' \times 11''$, in general use in the United States, and permits filing of small tracings and folded blueprints in commercial standard letter files.

For drawings made in the metric system of units or for foreign correspondence the metric standard trimmed sheet sizes may be used. These sizes are based on the width to length ratio of 1 to $\sqrt{2}$ and are as follows:

A0 841 × 1189 mm	A2 420 × 594 mm	A4 210 × 297 mm	A6 105 × 148 mm
A1 594 × 841 mm	A3 297 × 420 mm	A5 148 × 210 mm	

GLOSSARY OF SHOP TERMS FOR DRAFTSMEN

Anneal—To soften a metal piece and remove internal stresses by heating to its critical temperature and allowing to cool very slowly.

Arc-weld (*v*)—To weld by electric arc process.

Bore (*v*)—To enlarge a hole with a boring tool as in a lathe or boring mill. Distinguished from *drill*.

Boss—A projection of circular cross section, as on a casting or forging.

Braze—To join by the use of hard solder.

Broach (*v*)—To finish the inside of a hole to a shape usually other than round. (*n*) A tool with serrated edges, pushed or pulled through a hole to enlarge it to a required shape.

Buff—To polish with abrasive on a cloth wheel or other soft carrier.

Burnish—To smooth or polish by a rolling or sliding tool under pressure.

Bushing—A removable sleeve or liner for a bearing.

Carburize—To prepare a low-carbon steel for heat-treatment by packing in a box with carbonizing material, such as wood charcoal, and heating to about 2000° F. for several hours, then allowing to cool slowly.

Caseharden—To harden the surface of carburized steel by heating to critical temperature and quenching, as in an oil or lead bath.

Castellate—To form into a shape resembling a castle battlement, as castellated nut. Often applied to a shaft with multiple integral keys milled on it.

Chamfer—To bevel a sharp external edge.

Chase (*v*)—To cut threads in a lathe, as distinguished from cutting threads with a die. (*n*) A slot or groove.

Chill (*v*)—To harden the surface of cast iron by sudden cooling against a metal mold.

Chip (*v*)—To cut or clean with a chisel.

Color-harden—To caseharden to a very shallow depth, chiefly for appearance.

Core (*v*)—To form the hollow part of a casting, using a solid form made of sand, shaped in a core box, baked and placed in the mold. After cooling, the core is easily broken up leaving the casting hollow.

Counterbore (*v*)—To enlarge a hole to a given depth. (*n*) The cylindrical enlargement of the end of a drilled or bored hole. 2. A cutting tool for counterboring, having a piloted end of the size of the drilled hole.

Countersink (*v*)—To form a depression to fit the conical head of a screw, or the thickness of a plate, so the face will be level with the surface. (*n*) A conical tool for countersinking.

Crown—Angular or rounded contour, as on the face of a pulley.

Die—One of a pair of hardened metal blocks for forming, impressing or cutting out a desired shape. 2 (thread). A tool for cutting external threads. Opposite of tap.

Die Casting (*n*)—A very accurate and smooth casting made by pouring a molten alloy (or composition, as Bakelite) usually under pressure into a metal mold or die. Distinguished from a casting made in sand.

Die Stamping (*n*)—A piece, usually of sheet metal, formed or cut out by a die.

Draw (*v*)—To form by a distorting or stretching process. 2. To temper steel by gradual or intermittent quenching.

Drill (*v*)—To sink a hole with a drill, usually a twist drill. (*n*) A pointed cutting tool rotated under pressure.

Drop Forging (*n*)—A wrought piece formed hot between dies under a drop hammer, or by pressure.

Face (*v*)—To machine a flat surface perpendicular to the axis of rotation on a lathe. Distinguished from *turn.*

Feather—A flat sliding key, usually fastened to the hub.

Fettle—To remove fins and smooth the corners on unfired ceramic products.

File (*v*)—To finish or trim with a file.

Fillet (*n*)—A rounded filling of the internal angle between two surfaces.

Fin—A thin projecting rib. Also, excess ridge of material.

Fit (*n*)—The kind of contact between two machined surfaces, as (1) *drive, force* or *press*—when the shaft is slightly larger than the hole and must be forced in with sledge or power press.

(2) *shrink*—when the shaft is slightly larger than the hole, the piece containing the hole is heated, thereby expanding the hole sufficiently to slip over the shaft. On cooling, the shaft will be seized firmly if the fit allowances have been correctly proportioned.

(3) *running or sliding*—when sufficient allowance has been made between sizes of shaft and hole to allow free running without seizing or heating.

(4) *wringing*—when the allowance is smaller than a running fit and the shaft will enter the hole by twisting it by hand.

Flange—A projecting rim or edge for fastening or stiffening.

Forge (*v*)—To shape metal while hot and plastic by a hammering or forcing process either by hand or by machine.

Galvanize (*v*)—To treat with a bath of lead and zinc to prevent rusting.

Graduate (*v*)—To divide a scale or dial into regular spaces.

Grind (*v*)—To finish or polish a surface by means of an abrasive wheel.

Kerf (*n*)—The channel or groove cut by a saw or other tool.

Key (*n*)—A small block or wedge inserted between shaft and hub to prevent circumferential movement.

Keyway, or **key seat**—A groove or slot cut to fit a key. A key fits into a key seat and slides in a keyway.

Knurl (*v*)—To roughen or indent a turned surface, as a knob or handle.

Lap (*n*)—A piece of soft metal, wood or leather charged with abrasive material, used for obtaining an accurate finish. (*v*) To finish by lapping.

Lug—A projecting "ear" usually rectangular in cross section. Distinguished from *boss*

Malleable Casting (*n*)—An ordinary casting toughened by annealing. Applicable to small castings, with uniform metal thicknesses.

Mill (*v*)—To machine with rotating toothed cutters on a milling machine.

Neck (*v*)—To cut a groove around a shaft, usually near the end or at a change in diameter. (*n*) A portion reduced in diameter between the ends of a shaft.

Pack-harden—To carburize and caseharden.

Pad—A shallow projection. Distinguished from *boss* by shape or size.

Peen (*v*)—To stretch, rivet or clinch over by strokes with the peen of a hammer. (*n*) The end of a hammer head opposite the face, as **ball peen.**

Pickle (*v*)—To clean castings or forgings in a hot weak sulphuric acid bath.

Plane (*v*)—To machine work on a planer, having a fixed tool and reciprocating bed.

Planish (*v*)—To finish sheet metal by hammering with polished-faced hammers.

Polish (*v*)—To make smooth or lustrous by friction with a very fine abrasive.

Profile (*v*)—To machine an outline with a rotary cutter usually controlled by a master cam or die.

Punch (*v*)—To perforate by pressing a nonrotating tool through the work.

Ream (*v*)—To finish a drilled or punched hole very accurately with a rotating fluted tool of the required diameter.

Relief (*n*)—The amount one plane surface of a piece is set below or above another plane, usually for clearance or for economy in machining.

Rivet (*v*)—To fasten with rivets. 2. To batter or upset the headless end of a pin used as a permanent fastening.

Sandblast (*v*)—To clean castings or forgings by means of sand driven through a nozzle by compressed air.

Shape (*v*)—To machine with a shaper, a machine tool differing from a planer in that the work is stationary and the tool reciprocating.

Shear (*v*)—To cut off sheet or bar metal between two blades.

Sherardize (*v*)—To galvanize with zinc by a dry heating process.

Shim (*n*)—A thin spacer of sheet metal for adjusting.

Spin (*v*)—To shape sheet metal by forcing it against a form as it revolves.

Spline (*n*)—A long keyway. Sometimes, also a flat key.

Spot-face (*v*)—To finish a round spot on a rough surface, usually around a drilled hole, to give a good seat to a screw or bolthead. Cut, usually $\frac{1}{16}''$ deep, by a rotating milling cutter.

Spot-weld (*v*)—To weld in spots by means of the heat of resistance to an electric current. Not applicable to sheet copper or brass.

Steel Casting (*n*)—Material used in machine construction. Is ordinary cast iron into which varying amounts of scrap steel have been added in the melting.

Swage (*v*)—To shape metal by hammering or pressure with the aid of a form or anvil called a "swage block."

Sweat (*v*)—To join metal pieces by clamping together with solder between, and applying heat.

Tack-weld (*v*)—To join at the edge by welding in short intermittent sections.

Tap (*v*)—To cut threads in a hole with a tapered tool called a "tap," having threads on it and fluted to give cutting edges.

Temper (*v*)—To change the physical characteristics of steel by a process of heat-treatment.

Template, templet—A flat pattern for laying out shapes, location of holes, etc.

Trepan (*v*)—To cut an outside annular groove around a hole.

Tumble (*v*)—To clean, smooth or polish castings or forgings in a rotating barrel or drum by friction with each other, assisted by added mediums, as scraps, "jacks," balls, sawdust, etc.

Turn (*v*)—To machine on a lathe. Distinguished from *face*.

Undercut (*v*)—To cut leaving an overhanging edge. (*n*) A cut having inwardly sloping sides.

Upset (*v*)—To forge a larger diameter or shoulder on a bar.

Weld (*v*)—To join two pieces by heating them to the fusing point and pressing or hammering together.

GLOSSARY OF STRUCTURAL TERMS FOR DRAFTSMEN

Batten Plate—A small plate used to hold two parts in their proper position when made up as one member.

Batter—A deviation from the vertical in upright members.

Bar—Square or round rod; also flat steel up to 6 inches in width.

Bay—The distance between two trusses or transverse bents.

Beam—A horizontal member forming part of the frame of a building or structure.

Bearing Plate—Flat steel over 6 inches in width and over 2 inches in thickness.

Bent—A vertical framework usually consisting of a truss or beam supported at the ends on columns.

Brace—A diagonal member used to stiffen a framework.

Buckle Plate—A flat plate with dished depression pressed into it to give transverse strength.

Built-up Member—A member built from standard shapes to give one single stronger member.

Camber—Slight upward curve given to trusses and girders to avoid effect of sag.

Cantilever—A beam, girder or truss overhanging one or both supports.

Chord—The principal member of a truss on either the top or bottom.

Clearance—Rivet driving clearance is distance from center of rivet to obstruction. Erection clearance is amount of space left between members for ease in assembly.

Clevis—U-shaped shackle for connecting a rod to a pin.

Clip Angle—A small angle used for fastening various members together.

Column—A vertical compression member.

Cope—To cut out top or bottom of flanges and web so that one member will frame into another.

Coping—A projecting top course of concrete or stone.

Counters—Diagonal members in a truss to provide for reversal of shear due to live load.

Cover Plate—A plate used in building up flanges in a built-up member to give greater strength and area, or for protection.

Crimp—To offset the end of a stiffener to fit over the leg of an angle.

Diagonals—Diagonal members used for stiffening and wind bracing.

Dowel—An iron or wooden pin extending into but not through two timbers to connect them.

Driftpin—A tapered steel pin used to bring rivet holes fair in assembling steel work.

Edge Distance—The distance from center of rivet to edge of plate or flange.

Fabricate—To cut, punch and subassemble members in the shop.

Fillers—Either plate or ring fills used to take up space in riveting two members where a gusset is not used.

Flange—The projecting portion of a beam, channel or column.

Gage Line—The center line for rivet holes.

Gin Pole—A guyed mast with block at the top for hoisting.

Girder—A horizontal member, either single or built up, acting as a principal beam.

Girt—A beam usually bolted to columns to support the side covering or serve as window lintels.

Gusset Plate—A plate used to connect various members, such as in a truss.

Hip—The intersection between two sloping surfaces forming an exterior angle.

Knee Brace—A corner brace used to prevent angular movement.

Lacing or Lattice Bars—Bars used diagonally to space and stiffen two parallel members, such as in a built-up column.

Laterals—Members used to prevent lateral deflection.

Lintel—A horizontal member used to carry a wall over an opening.

Louvers—Metal slats either movable or fixed, as in a monitor ventilater.

Monitor Ventilator—A framework that carries fixed or movable louvers at the top of the roof.

Muntin—Parting strip in sash.

Panel—The space between adjacent floor supports, or purlins in a roof.

Pitch—Center distance between rivets parallel to axis of member. Also for roofs, the ratio of rise to span.

Plate—Flat steel over 6 inches in width and $\frac{1}{4}$ inch or more in thickness.

Purlins—Horizontal members extending between trusses, used as beams for supporting the roof.

Rafters—Beams or truss members supporting the purlins.

Sag Ties—Tie rods between purlins in the plane of the roof to carry the component of the roof load parallel to the roof.

Separator—Either a cast-iron spacer or wrought-iron pipe on bolt for the purpose of holding members a fixed distance apart.

Sheet—Flat steel over 6 inches in width and less than $\frac{1}{4}$ inch in thickness.

Shim—A thin piece of wood or steel placed under a member to bring it to a desired elevation.

Sleeve Nut—A long nut with right and left threads for connecting two rods to make an adjustable member.

Span—Distance between centers of supports of a truss, beam or girder.

Splice—A longitudinal connection between the parts of a continuous member.

Stiffener—Angle, plate or channel riveted to a member to prevent buckling.

Stringer—A longitudinal member used to support loads directly.

Strut—A compression member in a framework.

Truss—A rigid framework for carrying loads, formed in a series of triangles.

Turnbuckle—A coupling, threaded right and left or swiveled on one end, for adjustably connecting two rods.

Valley—The intersection between two sloping surfaces, forming a reentrant angle.

Web—The part of a channel, I beam or girder between the flanges.

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